New perspective in steelmaking activity to increase competitiveness and reduce enviromental impact

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The competitiveness of the European steel industry is strictly related to the introduction of high performance products and to the increase in process efficiency and to the reduction in environmental impact. These challenges can be faced to ensure a future to the area's important industrial assets and some actions need to be identified. Several aspects about steelmaking plants, processes and steel products have been highlighted and nowadays, they may become the object of innovative action and efforts in order to achieve and maintain a high level of competitiveness and to solve this serious industrial crisis.

Keywords: Steel-making - Iron ore DRI/HBI - Energy recovery - Slag recycling - Advanced High Strength Steel (AHSS)

INTRODUCTION

Steelmaking activities in the European Union are undergoing a significant transformation and need to adapt to new environmental requirements and new market challenges. Steelmaking activities are highly capital intensive and time-consuming and so the metamorphosis of plant configuration, process updating and innovation in the product mix have to identify the specific areas of intervention in order to establish a reliable hierarchy of the upgrading and innovation activities.
Several issues have been identified in the different steps of steelmaking:

- reduction of iron ore;
- energy recovery;
- efficient in-line rolling procedures;
- recovery of waste materials (i.e. slag and fume powders, etc.);
- development of innovative high performance AHSS (Advanced High Strength Steels).

The application of new processes and industrial techniques allow to make the steelmaking activities compliant with the new environmental addresses indicated by the international institutions without damaging or eliminating some industrial sectors but renewing them through new technologies.

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REDUCTION OF IRON ORE

The reduction of iron ore is a necessary operation in order to maintain a reliable chemical composition of the steels that have to be characterized by a low level of Cu and Sn which otherwise lead to problems of hot shortness during the rolling and forging operations. Thus, although the steelmaking route based on scrap recycling appears to be more environmentally friendly than the one starting from iron ore, the production of iron alloys starting from iron scrap is unavoidable to maintain a low concentration of Cu and Sn in the steel products. On the other hand, the traditional production route based on the use of iron ore is subject to increasing restrictions as regards emission levels, especially in terms of the dusts emission and of the aromatic polycyclic hydrocarbons (i.e. iso-benzo[a] pyrene). Such emissions are mainly associated with the production of coke and to the operating methods of the coke ovens. In particular, the new constraints[1)] imposed by the BAT (Best Available Techniques) conclusion in the European Union are particularly restrictive in terms of the dust emissions from the combustion chamber (<10mg/Nm^3) and from the coke cooling systems (<20mg/Nm^3) that nowadays is usually carried out in quenching towers. An alternative to the use of coke and coke ovens is represented by the production of pre-reduced iron (DRI-Direct Reduced Iron / HBI-Hot Briquetted Iron) from iron ore pellets through the exploitation of the natural gas that avoids the development of aromatic polycyclic hydrocarbons and

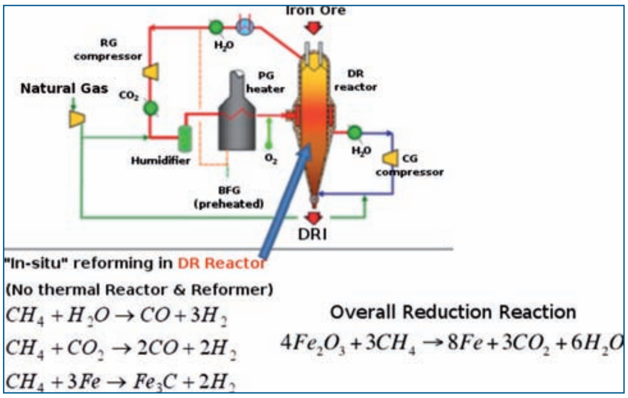

Fig. 1 - Layout of the process and the overall reduction reaction.

that decreases the CO_2 emissions, making the reduction process compliant with the recent European agreement of 26th October 2014, signed also by the Italian Government, which imposes a reduction of 40% in CO_2 emissions by 2030. In fact, the pre-reduction of the iron ore pellets to produce 1t of DRI/HBI implies a reduction of 63% of CO_2 if compared with the traditional route based on coal and coke exploitation (i.e. Blast Furnace, Corex, Rotatory Kiln Furnaces) (Figure 1).

At the moment there are two leading technologies for pre-reduction based on the natural gas exploitation: MIDREX® and HyL®. Both the technologies are based on reduction by CO and H_2 but in the MIDREX® process CO and H_2 are produced in a reformer and then introduced into the reduction reactor, whereas in HyL® a more recent approach is realized, because the natural gas is directly inserted into the reduction reactor and, at this stage, the formation of CO and H_2 takes place directly in the reduction reactor itself (Figure 2)[2)].

DRI/HBI is an extremely flexible raw material because it can be used in Electric Arc Furnaces to substitute high quality scrap or in the BOFs (Basic Oxygen Furnaces) as a coolant substituting steel scrap without affecting the chemical quality of the steel. Moreover, DRI/HBI can be added to the Blast Furnace to reduce coke consumption and simultaneously increase the production rate of the Blast Furnace. This option can be identified as a hybrid cycle, combining the Pre-reduction Process with the Blast Furnace: after the development of several experimental trials, a regular Blast Furnace Process can accept a maximum of 20% HBI or 25% DRI, because higher additions negatively affect the gas permeability of the Blast Furnaces (Figure 3). The hybrid configuration can represent a first stage opportunity for a soft and progressive conversion of the integrated Coke Ovens – Blast Furnace – Basic Oxygen Furnace to a steelmaking cycle characterised by a lower environmental impact.

The coupling of a pre-reduction system based on natural gas and the electric arc furnace (even with the possible hot charging of DRI/HBI) can highlight the best environmental performances compared with other technological routes (Table 1).

Nowadays, about 80Mt/year of DRI/HBI are produced

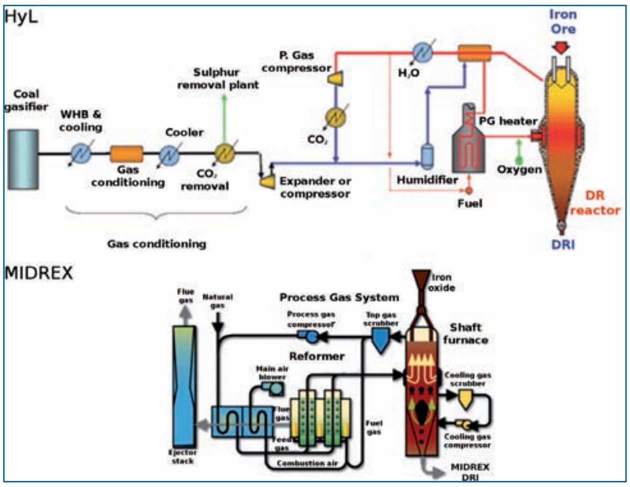

Fig. 2 - Scheme of HyL® and MIDREX® Processes.

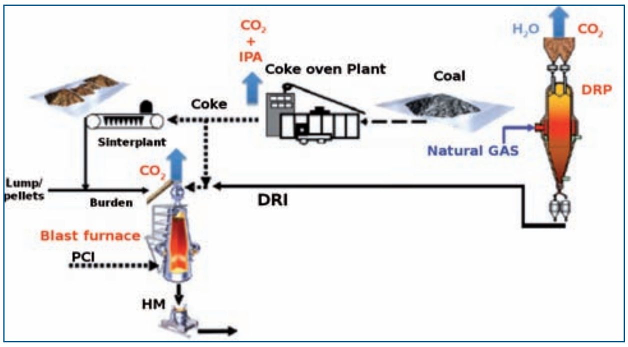

Fig. 3 - Hybrid configuration combining the pre-reduction route and the blast furnace (HM- Hot Metal pig iron /DRP Direct Reduction Process).

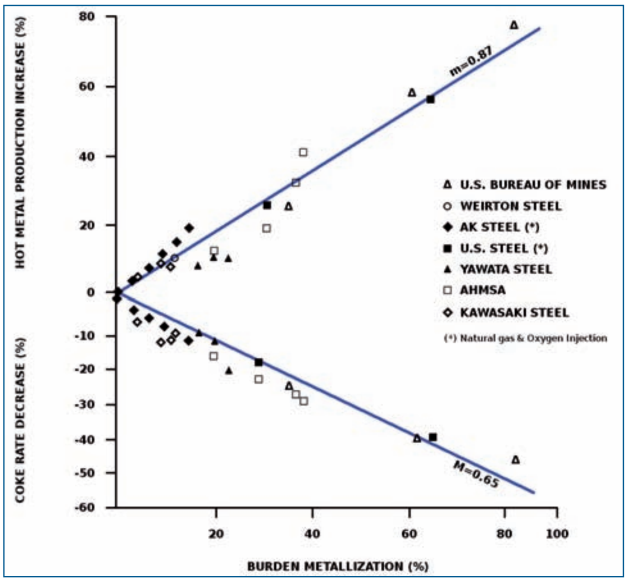

Fig. 4 - Reduction in coke consumption and increase in the production rate of the Blast Furnace as a function of DRI/HBI addition[3)].

* The computation of CO_2 emissions includes that for pre-reduction coupled with an electric arc furnace and also the average CO_2 production by Italian power generation plant for the use of electric arc furnace (EAF) and it does not take into account the increase in EAF efficiency associated with the charge of hot DRI/HBI.

** The performances shown for the so called FINEX/COREX route are affected by the use of coal that is not substituted by resources producing lower CO_2 and sulphur compounds emissions.

CO_2			
Traditional Cycle (After BAT 2012 application)	Hybrid Configuration (20% HBI addition)	100% Prereduction+EAF*	Corex/Finex
0%	-38%	-63%	+12.5%
Fine powders produced by coke ovens			
Traditional Cycle (After BAT 2012 application)	Hybrid Configuration (20% HBI addition)	100% Prereduction+EAF	Corex/Finex
-56%	-88%	-100%	-50%
PCCD/PCFD (dioxins) – The emission is associated with the sintering plant			
Traditional Cycle (After BAT 2012 application)	Hybrid Configuration (20% HBI addition)	100% Prereduction+EAF	Corex/Finex
-50%	-75%	-100%	-40%
SOx			
Traditional Cycle (After BAT 2012 application)	Hybrid Configuration (20% HBI addition)	100% Prereduction+EAF	Corex/Finex
-68%	-82%	-88%	-40%
NOx			
Traditional Cycle (After BAT 2012 application)	Hybrid Configuration (20% HBI addition)	100% Prereduction+EAF	Corex/Finex
-42%	-69%	-81%	-42%

Tab. 1 - Synthetic table on the reduction in polluting chemical substances compared with the current situation of polluting emissions from traditional iron ore reducing cycles based on coke ovens, Blast Furnaces and Basic Oxygen Furnaces.

worldwide with a projection to 120Mt by 2025[4]. In Europe there is only one old pre-reduction plant, installed in 1970 in Germany, and in 2013 it produced at its nearly maximum yearly rate of 500.000t. DRI/HBI can be profitably produced in Italy as a function of the price of natural gas:

- 0.29€/Nm^3 for hot charging in EAF
- 0.26€/Nm^3 for cold charging in EAF
- 0.22€/Nm^3 for use in Blast Furnace.

The prices, recorded on the Dutch Transfer Title Facility used to fix the natural gas price also by the Italian Authority for Energy and Gas, show price levels that make the pre-reduction route interesting (Figure 5).

Fig. 5 - Evolution of the gas prices in the European natural gas spot market (Dutch Transfer Title Facility). The price recorded on 2nd November 2014 is fixed at 0.193€/Nm^3.

ENERGY RECOVERY

The high prices of energy and decreasing of fossil fuel resources clearly show how the optimum application of energy, its consumption management, waste management and heat recovery methods for the re-use of waste heat are very important factors in steelmaking and rolling activities.

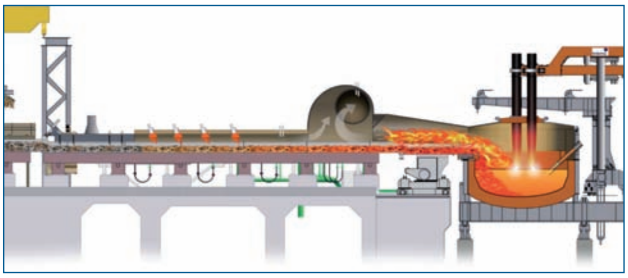

Fig. 6 - TENOVA Consteel Technology®: the outcoming fumes preheat the continuously charged steel scrap along the charging tunnel.

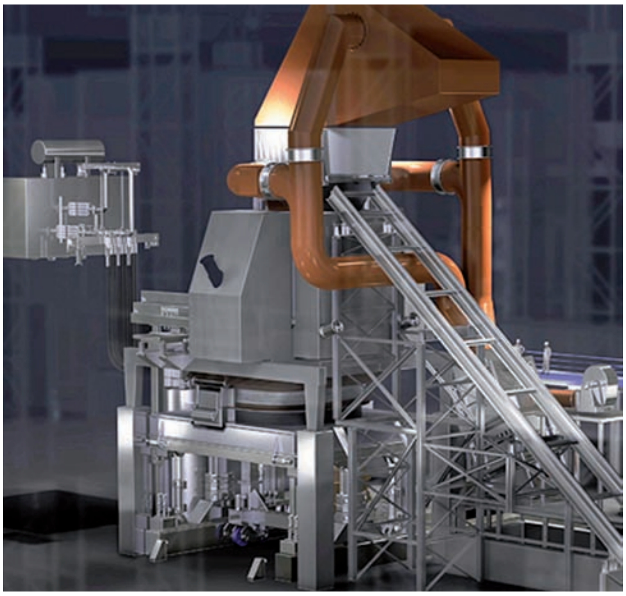

Fig. 7 - Simetal EAF QUANTUM Furnace® represents the latest evolution of the shaft furnace with the scrap basket, through which the hot fumes pass, located above the EAF.

A consequence of this scenario is represented by the increased interest in the efficient use of energy employed[5].
The steel industry is a highly energy- and resource- intensive sector where profit and efficiency are not the only targets. This industrial sector accounts for 15-20% of total industrial energy consumption and 5-10 % of total primary energy consumption.
Indeed, the responsibility towards society in terms of environmental impact needs to be taken into account. Thus, an increase in the energy efficiency of the industrial processes represents a favourable route for addressing environmental concerns and energy security[6,7].
The pre-heating of the scrap performed by the hot gases produced in the Electric Arc Furnace presents the most favorable opportunity for reducing energy consumption. Two main technologies are consolidated and can perform this operation: TENOVA Consteel® (Figure 6) and Simetal QUANTUM® Furnace (Figure 7).
In order to perform a correct estimation of the energy savings achieved by the pre-heating system, the base-line of the electric energy consumption has to be pointed out. A first evaluation can be found in the BREF[8] on steelmaking technologies published by the European Union in 2012 where average electric consumption is indicated in a range between 404kWh/t and 748kWh/t (Table 2).
In the BREF estimation, the EU Commission has not considered the furnace as a function of the final products and the categories of steel scrap used; this is why such a large range is indicated. On the basis of the AIST (Association for Iron and Steel Technology) 2013 Electric Arc Furnace Round Up[9], it is possible to estimate an average electric consumption of 462kWh/t (with a standard deviation of 67kWh/t) which is consistent with the data provided by the BREF, but is concentrated in the lowest part of the proposed range. If a distinction is made on the basis of the Electric Arc Furnaces producing only flat products (mainly concentrated in Northern, Central and Southern Americas):
• strips;
• plates;
• low carbon steels;
the estimation does not change much and average electric consumption is 457kWh/t. This estimation includes the average amount of 79kWh/t needed to raise the temperature of a low carbon steel and overheat it from the solidus temperature up to 1650°C, the temperature needed to tap the steel into the ladle. Thus, 457kWh/t can be considered a reliable base-line for specific electric power consumption and the pre-heating of the steel can allow a decrease of such a value in a range between 380kWh/t and 330kWh/t.
The specific electric power consumption base-line has to be coupled also with the average natural gas and carbon consumption to produce 465MJ/t[10] and the application of scrap pre-heating can decrease this specific average consumption to about 400MJ/t.
Energy savings can be obtained in the integrated cycle involving Coke Ovens – Blast Furnaces – Basic Oxygen Converters. There is a consolidated tradition in the exploitation of the gas derived from these plants, but more attention can be paid to the heat recovery during the discharging operation of the coke. Coke Dry Quenching (CDQ) is one of the most relevant systems adopted for energy and environmental optimization (Figure 8).

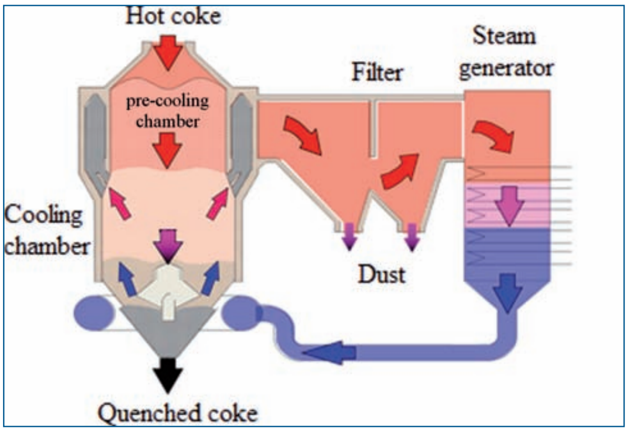

Fig. 8 - Layout of the Coke Dry Quenching System.

Input		
Raw materials		
Metallic input:		
Scrap	kg/t LS	1039-132
Pig iron	kg/t LS	0-153
Liquid hot metal[1]	kg/t LS	
DRI (HBI)	kg/t LS	0-215
Lime/dolomite[2]	kg/t LS	25-140
Coal (including anthracite and coke)	kg/t LS	3-28
Graphite electrodes	kg/t LS	2-6
Refractory lining	kg/t LS	4-60
Alloys:		
Carbon steel	kg/t LS	11-40
High alloy and stainless steel	kg/t LS	23-363
Gases		
Oxygen	m^3/t LS	5-65
Argon	m^3/t LS	0.3-1.45
Nitrogen	m^3/t LS	0.8-12
Steam[3]	kg/t LS	33-360
Energy		
Electricity	kWh/t LS MJ/t LS	404-748 1454-2693
Fuels (natural gas and liquid fuels)	MJ/t LS	50-1500
Water	m^3/t LS	1-42.8

Output		
Products		
Liquid steel (LS)	kg	1000
Air emissions		
Off-gas flow	MNm^3/h Nm^3/t LS	1-2 8000-10000
Dust	g/t LS mg/m^3	4-300 0.35-52
Hg	mg/t LS	2-200
Pb	mg/t LS	75-2850
Cr	mg/t LS	12-2800
Ni	mg/t LS	3-2000
Zn	mg/t LS	200-24000
Cd	mg/t LS	1-148
Cu	mg/t LS	11-510
HF	mg/t LS	0.04-15000
HCl	mg/t LS	800-35250
SO_2	g/t LS	5-210
NO_x	g/t LS	13-460
CO	g/t LS	50-4500
CO_2	Kg/t LS	72-180
TOC	g C/t LS	35-260
Benzene	mg/t LS	30-4400
Chlorobenzenes	mg/t LS	0.2-12
PAH[4]	mg/t LS	9-970
PCB[5]	mg/t LS	0.01-5
PCDD/F	µg I-TEQ/t LS	0.04-6
Production residues (waste/by-products)		
Slag from furnace	kg/t LS	60-270
Slag from ladle	kg/t LS	10-80
Dusts	kg/t LS	10-30
Waste refractories	kg/t LS	1.6-22.8
Noise	dB (A)	90-133

[1] Hot metal is only used in very special cases (about 275 kg/t LS), then the quantity of scrap is lower

[2] Typically lime is used but in a few cases dolomite alone is used or combinations of dolomite and lime (e.g. weight proportion 63/37)

[3] Steam is generally not used within EAF steelmaking, except for plants with secondary metallurgy with vacuum treatment

[4] No consistent database, some results represent the total of 16 EPAPAH, other only a section of them

[5] No consistent database, values represent different selections of PCB (2 of them refer to the above-mentioned Ballschmiter PCB, 3 to WHO-TEQ and 2 without further indication).

NB:

- Some measuring methodologies might vary significantly from country to country ad from plant to plant. Not all the emitted substances are measured at all plants. The measuring programs vary greatly depending on permit requirements.
- Data has been compiled from information provided by EAF melt shop operators (carbon steel, alloy steel and stainless steel) representing 37.4 Mt of steel produced. This represented close to 50% of the total EAF steel production in the EU in 2004 in 11 different EU countries.
- LS = Liquid steel

Source: [140, Eurofer 2009] [200, Commision 2001] [220, Eurofer 2008] [234, Poland 2007] [367, Prum et al. 2005] [371, Eurofer 2007] [372, Czech TWG member 2008].

Tab. 2 - Input and Output mass and energy flows for an Electric Arc Furnace-

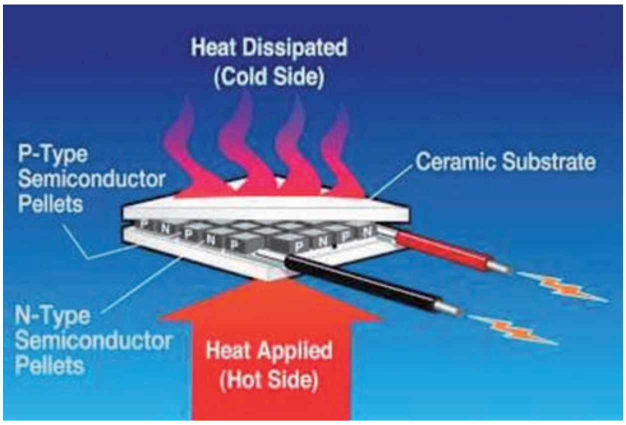

Fig. 9 - Layout of a thermoelectric module.

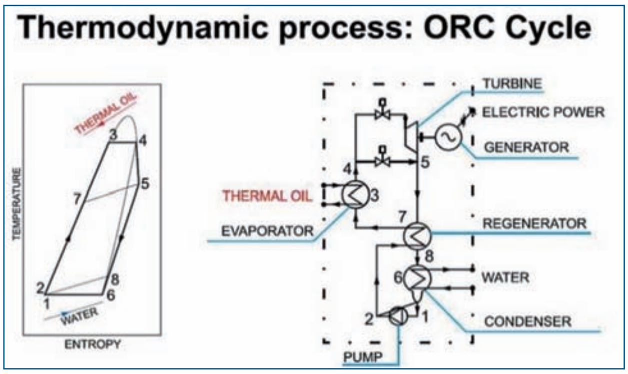

Fig. 10 - The thermodynamics of ORC.

In the traditional process the hot coke had to be taken out of the coke oven and cooled directly with water in the cooling tower, causing valuable energy dissipation into the atmosphere and producing a dispersion of powders. The CDQ plant consists in three dry quenching chambers, their associated waste heat boilers and the charging cranes. Coke is cooled in these chambers by means of circulating gas composed mainly of nitrogen and other inert gases. The temperature of the circulating gas at the outflow section from the chamber is about 1050 °C. Coke flows through the chamber in about 5 hours and the flow rate of circulation gas is about 75000 Nm^3/h.
The nominal capacity of the current dry quenching plant is 150t/h (50t/h for chamber). A unit working at full capacity produces about 25t/h of high-pressure steam (93 bar) and a unit as warm reserve about 2.5t/h of low-pressure steam (8 bar). The effects of this particular treatment are very important because of the great capacity of electric power production; a treating capacity of 100 t/h produces about 18 MW of electric power. In terms of protection of the global environment, CDQ does not produce greenhouse gas (CO_2). Reduction of CO_2 by CDQ is nearly equivalent to 18t/h for a power generation of 18 MW[11].
Instead, the recovery of relatively low temperature heat in all metallurgical and steelmaking plants can be achieved by the exploitation of thermoelectricity. The direct conversion of heat energy into electricity or the reverse power generation by a semi-conductor thermoelectric power generator device is related to electron transport phenomena, and the interrelated Seebeck, Peltier and Thomson effects (Figure 9). Thermoelectric devices generate voltage in presence of a temperature gradient. The interest in these devices comes from the large number of advantages, such as the absence of moving components and lower maintenance. Lead chalcogenides, most notably lead selenide (PbSe) and lead telluride (PbTe), have become an active area of research due to their thermoelectric (TE) properties. The high merits of these materials has brought much attention to them, due to their aptitude for converting waste heat into electricity. Lead telluride (PbTe) and related compounds, alloys and composites have the highest ZT values and are the TE materials with the highest potential for power generation and energy conservation over the intermediate temperature range (500–800 K)[12]. The use of such systems in European metallurgical and steelmaking plant is covered by the international patent BS2013A000096 that also shows an example of the realized system.
Energy optimization can be also achieved through steam recovery (e.g Tenova iRecovery®) that is used in the ORC

Fig. 11- Example of Turboden ORC turbine equipment.

(Organic Rankine Cycle) turbine (Figure 10, Figure 11). Some plants, such as Georgsmarienhütte, use heat recovery with off-gas temperatures down to 600 °C, whereas Feralpi Siderurgica S.p.A. heat recovery is designed down to 200 °C with additional control of the downstream oxygen content and it is connected to the off-gas treatment of electric furnace melting system. The recovered energy reduces net power consumption, allowing significant reduction of CO_2. In addition to electricity production, the remaining portion of the steam is fed into the Riesa Municipal steam supply system and used in a nearby tyre factory production process[13].
Environmental improvements can be also achieved thanks to the technological solutions inherent in in-line rolling technologies, as in the consolidated Arvedi ESP process where the liquid steel is cast and rolled into coils in a completely in-line system, without the cooling of semis to ambient temperature. In the Arvedi ISP (In-line Strip Production) line the time from the pouring of the liquid steel into the casting machine up to the coiling stage is only 15 minutes and this time has been further decreased to 7 minutes for

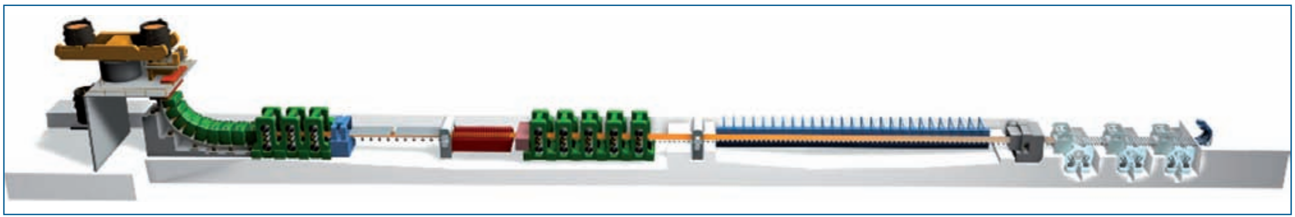

Fig. 12 - Lay-out of the Arvedi ESP process (from the continuous casting machine to coiling).

the Arvedi ESP (Endless Strip Production) line (Figure 12). Arvedi technology maximizes the use of the heat contained in the liquid steel (over the cycle the temperature never drops below 900-950°C) ; this involves a considerable energy saving , estimated at about 22t of oil equivalent (TOE) saved every 1000t of rolled product with a corresponding reduction of about 40% of CO_2 emissions.
For the cold rolling lines (including cold rolling, annealing furnaces and skinpass) the possibility of energy recovery appear very poor[14)], although the energy consumption of such lines are characterized by:

- 0.9GJ/t (0.02TOE/t) for cold rolling;
- 0.017GJ/t ($4 \cdot 10^{-4}$TOE/t) for skinpass operation.

RECOVERY OF SLAG AND WASTE MATERIALS

In every metallurgical process the production of a great amount of slag is implied. The industrial world struggled long in order to design a practical application for this waste, however this effort is often hindered by different applicative problems. In particular, steel production is accompanied by large volumes of slag and smaller quantities of other kinds of waste including dust, secondary metallurgy slag and refractories, and their safe disposal represents one of the major costs that the steelmakers have to face. For these reasons, steel-makers started to design advantageous ways to re-utilize these kinds of waste in different fields of application, not only those strictly related to the steel industry.
The re-use of these kinds of waste has become practice in Europe and in all the major developed countries of the World, in response to the need and the pressure to create a model of sustainable development, based on reducing the consumption of natural resources and minimizing the production of waste.
Many of these residuals, once considered waste and therefore disposed of with high costs and high environmental impact, have started and completed a virtuous cycle of development and transformation, becoming a precious alternative resource.
These by-products are good substitutes or complementary materials to products derived from natural resources. Thanks to the development of controlled production processes, based on the best available technologies, high quality by-products can be obtained, in agreement with the standard of civil engineering application fields (road construction, concrete production, etc.).

The exploitation and use of recycled waste by-products has manifold benefits, especially from the environmental point of view:

- reduction of the waste fraction sent to landfills;
- reduction of the exploitation of natural resources;
- reduction of activities impacting the territory (i.e. extraction and drilling);
- energy saving and reduction of CO_2 emissions.

Since 72% of the Italian steel market is supplied by Electric Arc Furnace (EAF) production, EAF slag recycling is a very topical issue both for steel-makers and scientists who are studying advantageous ways to reduce the environmental impact of this slag while also expanding the possibility of its use in civil engineering applications as a replacement for conventional materials[15,16,17,18,19)].
Since electric steel slag can be considered in the same way as natural hard rocks, this by-product could be successfully used to replace inert material in several areas, allowing disposal costs to be reduced and giving it a new value.
Steel slag, after maturation, undergoes a two-phase crushing process, the first carried out with a jaw crusher and then finished with a cone crusher. Through the stages of curing, crushing and sieving, the raw slag is converted into a product usually divided into three different size fractions: sand and gravel (size 0-4 mm), gravel (4-8 mm) and gravel and crushed stone (8-12 mm). The entire production process is tightly integrated with the steelmaking process and the subsequent derivate civil uses are compatible with Italian environmental legislation, materializing the spirit of "Zero Waste" that the steel industry has pursued over the last decade.
The fields where processed slag can be applied are differentiated according to the demands of the market, and the operators have at their disposal a material that not only fully meets the technological conditions required by the application, but also carries a considerable saving of natural resources. Average production of electric furnace slag in Italy amounted to more than 3 million tons per year in the period 2008-2010. More than 75% of the slag is used for aggregates production for civil engineering applications[20)]. A smaller percentage is destined for the manufacture of concrete, where slag is principally used as a filler or inert aggregate (Figure 13). These data are consistent with European production and use of steel slag[21)].
Although EAF slag has interesting chemical and mechanical properties, due to the high content of heavy metals

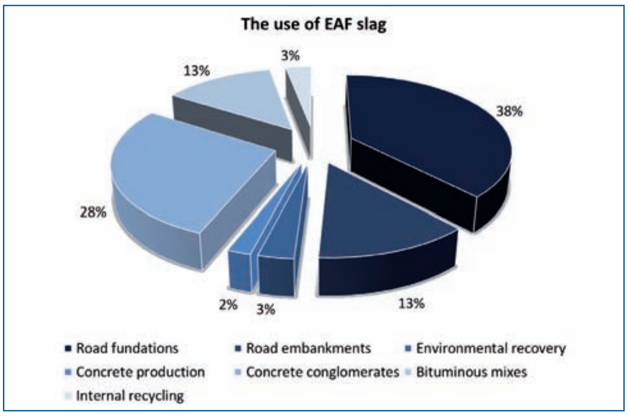

Fig. 13 - Main application of recovered inert slag.

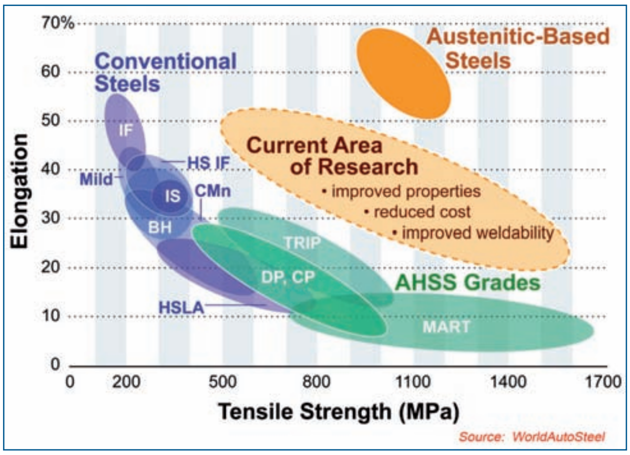

Fig. 14 - Relation between elongation (ductility) and tensile strength in low carbon steel for general applications.

(Ba, Cr, V, etc.), this slag is classified as hazardous waste and is normally disposed of in special, expensive landfills, which limits its re-use.

Different techniques are available to stabilize the slag and reduce the heavy metal leaching[22,23,24,25], mainly based on the addition of Cr-bearing additives, but no solutions have been found to cope with the other main problems afflicting slag (dust and volume instability).

Recently, a simple but effective method to stabilize this slag has been developed, inhibiting the leaching of all the dangerous heavy metals while simultaneously avoiding the swelling and pulverization of the treated mass[26]. This stabilization process is based on the addition of pure quartz into the slag stream during the deslagging operation. This technique has been installed inside a steelmaking plant and the stabilized EAF slag does not manifest any leaching after the chemical treatment, leading to the design of a feasible operating condition to produce a continuous flux of modified slag with a specific composition and properties and providing an opportunity to compete with traditional raw materials used for road construction or the manufacture of concrete.

INNOVATION IN STEEL GRADES

Conventional low carbon steels are eroding the special steels market due to the optimum compromise of their mechanical properties (strength, ductility and toughness) and weight, volumes and costs[27].

The most interesting mechanical properties in these applications are strength (fundamental in load capacity), elongation (a good index for plastic formability) and toughness (energy absorption and resistance against the development of cracks promoted by the presence of a defect). As is shown in the graph (Figure 14), conventional steels are characterized by high tensile properties but low strength compared with other steel classes[28].

The automotive sector is a very interesting example of the competition among steel producers and high performance requirements of car and truck manufacturers. The fast evolution in the automotive sectors has implied higher performances strictly related to the increase in loads and operating forces.

IF (Interstitial Free), DP (Dual Phase) or the so-called TRIP/TWIP (Transformation or Twinning Induced Plasticity) steels have been developed. The increase in the material's mechanical properties corresponds to the increase in load capacity and to the consequent possibility of reducing cross sections of the components, implying an obvious savings in terms of weight and volumes.

Weight reduction (up to 25%) plays a fundamental role in competitiveness because of the lower costs and a big reduction in emissions. These steels are characterized by high mechanical strength associated with a good formability enhancing the component resistance to stresses and to the impulsive load (impact).

The on-going researches on new steels combining both high resistance properties and ductility have lead to the development of Dual Phase steels. Their typical microstructure, composed by a 20% - 25% finely dispersed hard martensitic phase within a soft ferritic matrix, grants the combination of the properties of both these phases reaching great ductility, work hardening and tensile strength (Figure 15). The achievement of these results has been obtained exploiting the coupled effects of dislocation pinning and stress relief consequent to the martensitic transformation. Moreover through the proper thermal treatment the phase ratio can be tuned, reaching the desired combination of mechanical properties to satisfy the application requirements[29].

Following this research path further progress has been also made through the realization of Complex Phase steels (CP)[30].

On the other hand, the mechanical properties enhancements have been achieved also via a different route, taking advantage of the staking fault energy which can be stored within the steels through the lattice imperfections. Since this "latent" energy reaches the highest values in face-centered cubic lattices and in hexagonal close-packed lattices, steels have to possess the austenitic structure in order to exploit these phenomena.

In detail, TRIP steels (TRansformation Induced Plasticity)

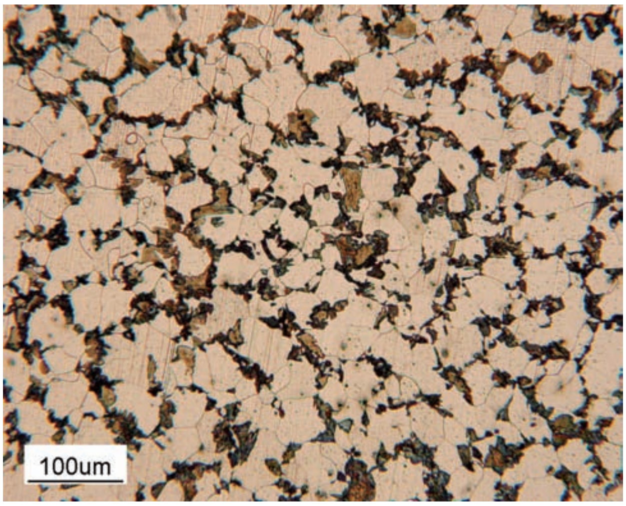

Fig. 15 - Dual Phase steel microstructure: finely dispersed hard martensitic phase (colored grains) within a soft ferritic matrix (white grains).

own finely dispersed small grains of retained austenite (up to 15%) which absorb the energy produced by a load via the activation of the martensitic transformation. This behavior can be developed by two mechanisms: the diffusionless Magee effect at low temperatures and the Greenwood-Johnson effect, involving diffusive phenomena, at higher temperatures[31].

On the other hand, TWIP steels (TWinning Induced Plasticity) exploit the mechanical response of face-centered cubic lattices, the generation of mechanical twins, in order to produce a strong grain refinement. As a consequence, this effect acts directly on the dislocation average free path and hinder the dislocation movements[32].

Nowadays, research is moving towards high strength steels assisted by good tensile properties in order to substitute, in some dedicated and particular applications, alloys that are more expensive, for example Ti-alloys or Al-alloys. For this, austenitic steels, MBIP (Microband-Induced Plasticity), shape-memory steels and high Mn-steels are becoming a strategic target (Figura 16). This topic can be represented graphically (Figure 14) where these advanced high strength steel grades occupy the upper-left area, steels characterized by high strength and high elongation.

The continuous improvement in material properties is consistent with the will to increase energy efficiency and consequently reduce emissions. The study, research and production of steels characterized by high strength and ductility performance is a target to be achieved in order to maintain a good competitiveness for steel products in an area of the market that does not suffer from overcapacity, unlike construction steels, etc..

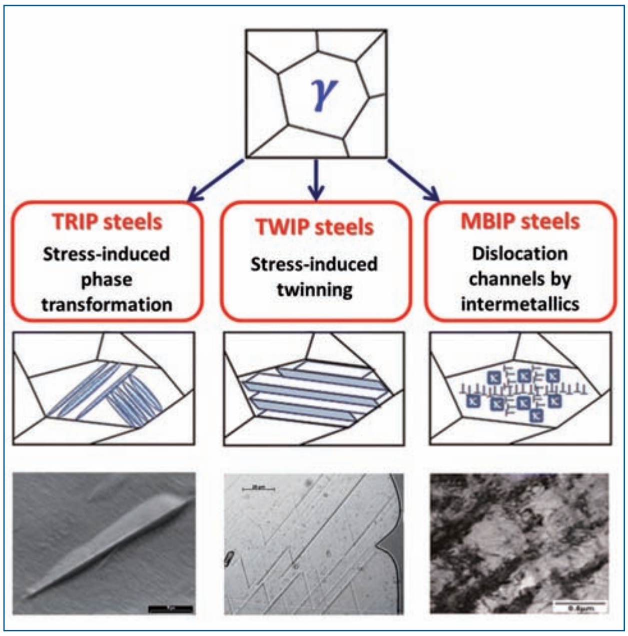

Fig. 16 - Strengthening phenomena featured in austenitic-based steels.

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