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Influence of direct-reduced iron percentage in EAF charge mix on EAF operation parameters

The effect of direct reduced iron (DRI) addition in metallic charge on the different steel making parameters and consumption figures have been studied. Data obtained from industrial heats carried out in 185-ton electric arc furnace (EAF) were used to study. The present study carried out in a wide range of DRI percentage, 0 - 50% of metallic charge, and the results have been statistically analyzed to correlate the percentage of DRI with the different consumption figures of electric energy, oxygen, coke and fluxing materials. In addition, the influence of DRI percentage on contents of tramp and detrimental elements affecting on steel quality has been also investigated.

The results reveal improving the steel quality by increasing DRI percentage, as the tramp elements (Cu, Sn, Ni, Cr) and detrimental elements (P, S) and also nitrogen, all decrease by increasing the percentage of DRI in the metallic charge. On the other hand, the increase in DRI percentage leads to increase in the consumptions (per ton of liquid steel) of electric energy, oxygen, coke and fluxing materials. Furthermore, the metallic yield decreases and the power on time and hence the tap-to-tap time increase as DRI percentage increases. With using higher DRI percentage in the charge, the yield strength and ultimate tensile strength of produced hot rolled bars of low carbon steel slightly decrease whereas elongation increases.

1. Introduction

Till the end of November 2013, about 1447 Mio tones steel was produced world-wide in 2013 [1]. Electric Arc Furnace (EAF) operations have improved significantly over the past 30 years. Due to shortage and availability of scrap, the use of direct reduced iron in EAF increased. Ezz Flat Steel (EFS) which located in Ain Sokhna, Suez, Egypt has an annual capacity of 1.2 million tones of molten steel using scrap and direct reduced iron (DRI) as raw materials. One of the directions towards achieving high production and high quality steel was improvement in the chemical energy utilization system. Key features are as follows:

(i) Electric arc furnace (EAF) of 185 tones tapping capacity equipped with 133 MVA transformers with three bottom porous plugs for argon purging and Eccentric Bottom Tapping (EBT). The EAF has three jet modules and one burner mounted on upper shell for oxygen, natural gas, and carbon injection.
(ii) A ladle furnace with a 28 MVA transformer and equipped with two bottom argon porous plugs and top wire feeders
(iii) A flexible thin slab caster to cast 70 mm slabs in wide range of casting speeds and steel grades
(iv) A hot strip mill connected to the this slab caster with tunnel type reheating and soaking furnace, slab descaling, roughing mill, transfer bar cropping and descaling, finishing mill (six 4-Hi stands with shifting and bending, equipped with crossing technology under rolling load conditions),laminar cooling and coiling of strip.
(V) Continuous casting machine with 6 strand , casting speed up to 4.5 m/min and copper mould 130*130 to produce steel billets from 8 up to 12 meter.
(Vi) Two Bar mill with 18 stands to roll rebar from 10 mm up to 32 mm with 500,000 ton/year capacity.

The present work deals with the effects of percentage of direct reduced iron in EAF charge mix on steel making operation parameters for 1350 heats. The mechanical properties for hot rolled rebar 16 mm also investigated.

Very often, large amounts of ore based scrap substitute materials such as direct reduced iron (DRI) pellets, hot briquetted iron (HBI), iron carbide, etc. are used when producing steels with low residual elements via EAF steel making. At the present time, the most common forms of direct reduced scrap substitute materials are DRI and HBI. DRI is produced from a combination of pelletized and lump ore, which is reduced in a shaft furnace such as in the Midrex , HYL processes by reformed natural gas [4],[7]. The DRI product is therefore a pellet material with a large amount of internal porosity and a very low bulk density.HBI is currently produced via two major process routes. By one process route, reduced DRI pellets can be fed while it is hot (650°C minimum) [3] from the reducing furnace into a briquetting machine.

HBI is also produced directly from ore fines via processes such as Finmet and Circored in which the ore fines are reduced in a series of fluidized bed reactors and then compacted into dense briquettes.DRI known as sponge iron due to its porosity.

Physically compacting the pellets into larger briquettes greatly decreases the porosity of the material and increases the bulk density.

Generally, the chemical properties of DRI and HBI sold commercially today are very similar. Nearly all commercial direct reduced materials contain between 80 to 90 percent metallic iron, 5 to 10 percent iron oxide, 5 to 10 percent gangue, and 0 to 4 percent carbon. The term gangue is used to describe the unreduced components of the mineral ore, including silica, alumina, lime, magnesia, etc.

2. Experimental work

2.1. Practice of steelmaking with direct reduced iron and scrap

First, EAF will be charged by first bucket of scrap, the bucket contains light scrap, medium scrap and pig iron. The average weight of scrap is changed in bucket from 20 to 110 ton according to steel grade will be produced. Melting of this bucket at temperature 1570-1590°C for 15-20 minutes accompanied with oxygen injection, natural gas through burners to help in melting the scrap, slag building (lime and dolomite) added. After that The EAF charged by the second bucket of scrap which weight about 55-65 ton, melting takes place for 5-10 minutes. At the end of second bucket meltdown, lime and dolomite added into EAF and/or DRI/HBI feeding takes place for 5-20 min. by weight 30-110 ton according to the charge mix, foaming the slag started and more slag building added. After that refining step takes place at 1600-1640°C by adding lime, de-slagging step occurs. The final step is tapping the molten steel by about 185 ton at temperature 1645-1660 °C.

The produced heats with different charge mix from 0% up to 50% DRI/HBI have been investigated. The last EAF sample chemical analysis, slag sample analysis, mechanical test results ,the recorded consumptions of coke, lime, total flux, oxygen ,electrical energy, chemical energy and power on time, related to each heat charge mix were interpreted.

Due to the great similarities of DRI and HBI, this large group of materials will be referred to generally as DRI/HBI for most of this work [4].

The average composition of DRI and HBI used in this present investigation are given in tables 1 and 2.

3. Results and discussion

3.1. Effect of DRI/HBI ratio in charge mix on the detrimental and tramp elements in steel

Fe_{metal}	Fe_{totl}	Degree of metallization	S%	P%	C%
85.5	91.45	93.5	0.0027	0.05	2.6

Table 1: Average chemical composition DRI pellets

Fe_{metal}	Fe_{total}	Degree of metallization	SiO2 %	CaO %	Total gangue %	S%	P%	C%
83.94	90.4	92.9	4.4	1	5.24	0.006	0.03	1.3

Table 2: Average chemical composition of HBI lumps

Sample	P%	S%	Cr%	Ni%	Cu%	Sn%	(Cr+Ni+Cu+Sn) %
1	0.014	0.051	0.118	0.159	0.55	0.0182	0.8452
2	0.018	0.053	0.124	0.125	0.543	0.0205	0.8125
3	*0.026*	*0.047*	*0.168*	*0.15*	*0.518*	*0.018*	*0.854*
4	0.048	0.051	0.2	0.114	0.466	0.02	0.8
average	0.0265	0.051	0.153	0.137	0.52	0.019	0.83

Table 3: Level of impurities and residual elements in scrap charge samples

C%	Si%	Mn%	P%	S%	Cr%	Ni%	Cu%	Mo%
4.9	0.45	0.59	0.07	0.051	0.065	0.02	< 0.01	0.05

Table 4: Average chemical composition of pig iron samples

CaO%	SiO2%	Fe2O3%	MgO%	Al2O3%	MnO%	P2O5%
34.97	18.77	24.53	7.9	8.4	2.37	0.57

Table 5: Average Chemical composition of investigated EAF slag

3.1.1 Sulfur and Phosphorous

DRI/HBI is normally of high purity. Therefore, the source of residual metals like Cu, Ni and Cr, and of other elements as P and S in a bath of molten metal with DRI/HBI and scrap is practically the scrap itself. Accordingly, an increase in DRI/HBI in the metallic charge leads to a decrease in the concentrations of the above mentioned elements in the steel.

The effect of DRI/HBI ratio in the EAF charge on S% and P% in steel is shown in fig. 1 and 2. The sulfur content decreased linearly from 0.051 to 0.042% when DRI/HBI % in EAF charge mix increases from 0 to 40%. The decrease in S mass % can be calculated from equation 1

$$S\ \text{mass}\ \% = 0.051 - 0.000227(DRI/HBI)\ \%\ \text{in EAF charge mix} \qquad (1)$$

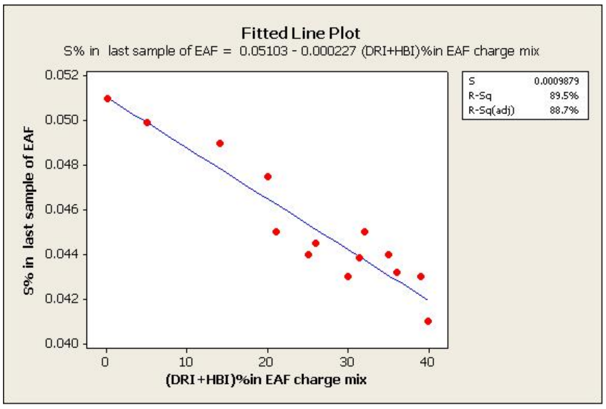

Fig.1: Effect of DRI/HBI on Sulfur mass% in final EAF molten steel sample

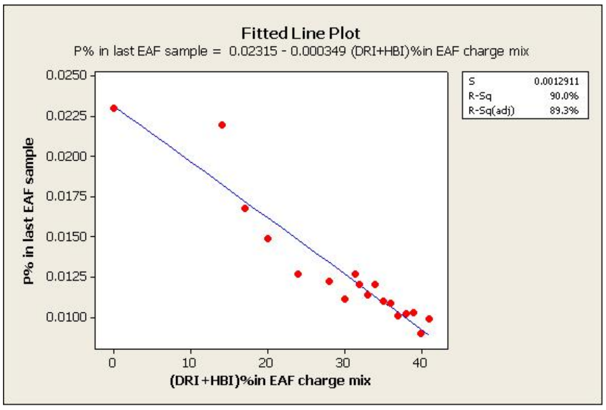

Fig. 2: Variation of P % in Last EAF vs. (DRI/HBI) % in EAF charge mix

The P% in last EAF sample decreased from 0.0232 to 0.0092% when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig. 2.

The phosphorous in last EAF steel sample can be calculated by the following equation:

P% mass in last EAF sample = 0.02315 – 0.000349 (DRI/HBI) % in EAF charge mix

(2)

3.1.2. Chromium and Nickel

Cr% in last EAF sample decreases linearly from 0.1254 to 0.0698% when DRI/HBI % in EAF charge mix increases from 0 to 40% as shown in Fig.3.The decrease in Cr mass % in the final steel sample can be calculated by the following equation:

Cr mass % in last EAF sample = 0.1254 –0.001390 (DRI/HBI) % in EAF charge mix

(3)

Ni % in last EAF sample decreases from 0.1293 to 0.086% when DRI/HBI % in EAF charge mix increases from 0 to 40% as shown in Fig.4. The decrease in Ni mass % in the final steel sample can be calculated by the following equation:

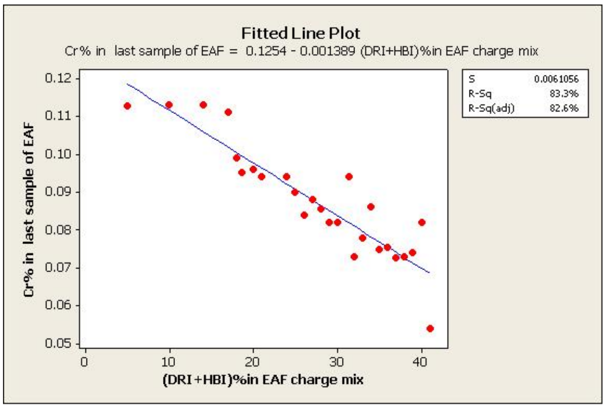

Fig. 3: Cr% in last EAF vs. (DRI/HBI) % in EAF charge mix

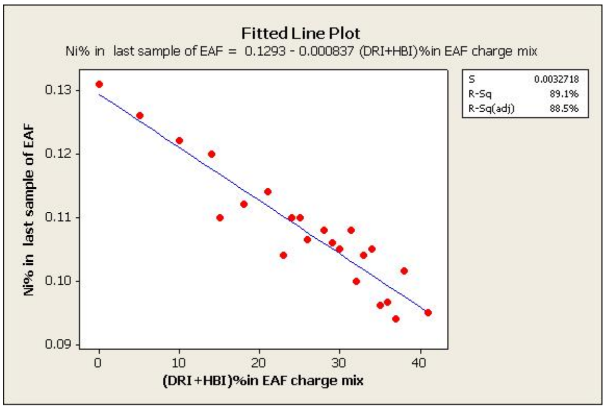

Fig.4: Ni% in last EAF vs. (DRI/HBI) % in EAF charge mix

Ni mass % in last EAF sample = 0.1293 – 0.0010837 (DRI/HBI) %in EAF charge mix

(4)

3.1.3. Tin and Copper

Sn % in last EAF sample decreased from 0.02137 to 0.01309% when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig.5. The tin% in EAF sample can be can be calculated by the following equation.

Sn % in last EAF sample = 0.02137 – 0.000207(DRI/HBI) % in EAF charge mix

(5)

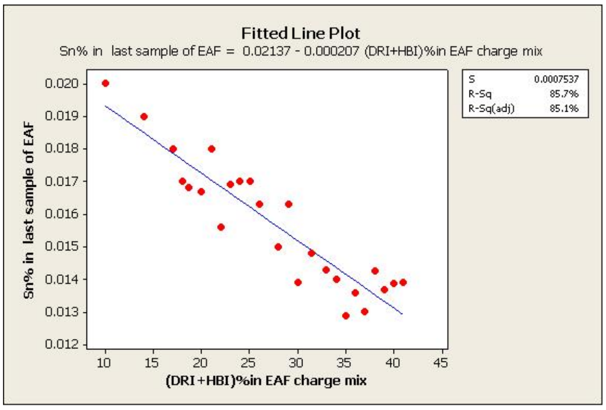

Fig.5: Tin % in last EAF vs. (DRI/HBI) % in EAF charge mix

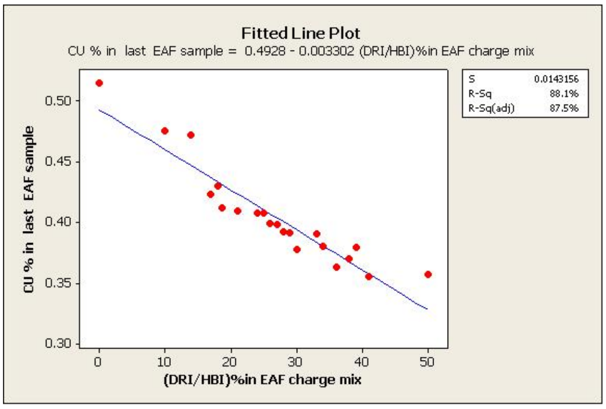

Fig.6: Cu% in last EAF sample vs. (DRI/HBI) % in EAF charge mix

Cu % in last EAF sample decreases from 0.4928 to 0.36 % when DRI/HBI % in EAF charge mix increases from 0 to 40% as shown in Fig.6. Copper in last steel sample can be calculated by the following equation:

Cu % EAF sample = 0.4928−0.003302 (DRI/HBI) % in EAF charge mix

(6)

3.1.4. Total residual elements

Total tramp elements percentage (Cr+Ni+Cu+Sn) % in last EAF sample decreased from 0.7736 to 0.5572% when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in fig.7.

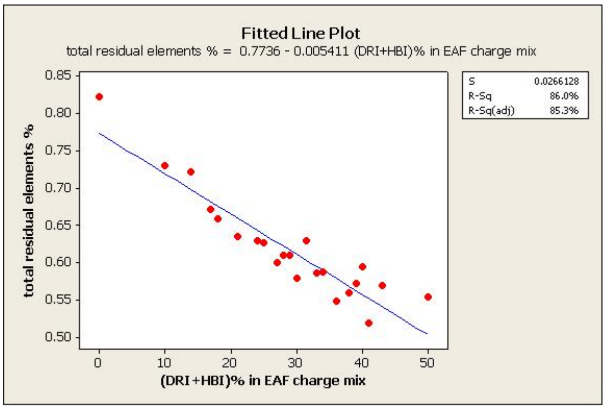

Fig.7: Variation of total residual elements % in last EAF vs. (DRI/HBI) % in EAF charge mix

The total tramp elements in final steel sample can be calculated by the following equation:

(Cr+Ni+Cu+Sn)%=0.7736−0.005411 (DRI/HBI) % in EAF charge mix

(7)

For the production of high quality steel grades from scrap with varying quality and chemical composition, the compliance with high purity levels is sometimes only achieved with dilution of unwanted tramp elements as Pb, Cu, Cr, Ni, Mo, and Sn with highly pure substituting material direct reduced iron [7].

3.2 Effect of DRI/HBI ratio in charge mix on lime, total flux consumption and EAF Slag quantity

3.2.1 Lime consumption

DRI/HBI usually contains silica as the main gangue constituent together with low levels of other impurities such as sulfur and phosphorus. According to the concentrations of these components in the DRI/HBI and the proportion of DRI/HBI in the metallic charge, varying quantities of lime must be fed into the furnace in order to slag the silica and remove the sulfur and phosphorus to the allowable levels of these elements for the grade of the steel to be produced.

Total lime consumption, kg/t of tapped steel during EAF operation steps (melting, DRI feeding and refining) calculated and investigated versus variation of DRI/HBI % in EAF charge mix. It is found that lime consumption increased from 60 to 78 kg/ ton molten steel when DRI/HBI ratio increased from 0 to 40% in EAF charge mix as shown in Fig. 8.

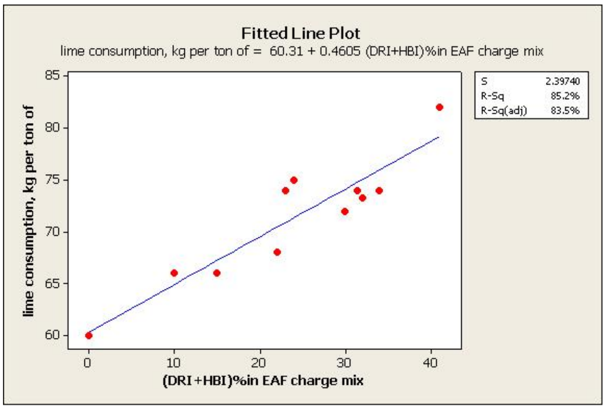

Fig. 8: Lime consumption in EAF operation vs. (DRI/HBI) % in EAF charge mix

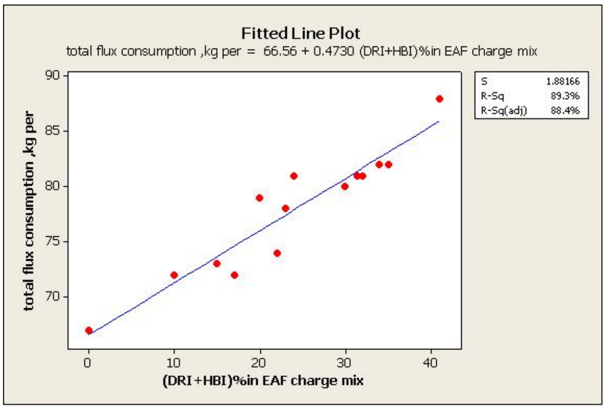

Fig.9: Total flux consumption in EAF vs. (DRI/HBI) % in EAF charge mix

The required lime for charge mix contains

DRI/HBI can be calculated by the following equation:

Lime, kg/t = 60.31 + 0.4605 (DRI/HBI) % in EAF charge mix

(8)

According to equation (8) an increase of 10% in (DRI/HBI) ratio in charge mix leads to an increase in lime consumption by 4.6 kg/t of liquid steel.

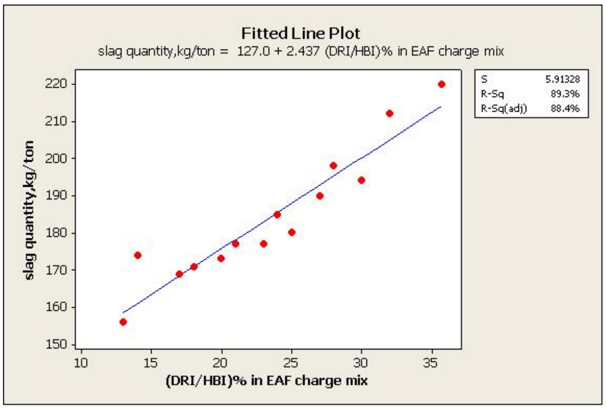

Fig. 10: EAF slag quantity vs. (DRI/HBI) % in EAF charge mix

3.2.2 Total flux consumption

The total flux (lime, dolomite and MgO) consumption, kg/t of tapped steel during EAF operation steps calculated and investigated versus variation of DRI/HBI % in EAF charge mix and it seen is that the total flux consumption increased from 66 to 85, kg /t molten steel as DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig. 9. Total flux consumption, kg per ton can be calculated from Equation (9) as follows

Total flux consumption, kg /t = 66.56 + 0.4730 (DRI/HBI) %in EAF charge mix

(9)

3.2.3 Slag quantity and DRI /HBI percentage in EAF charge mix

Slag quantity, kg/t of liquid steel calculated as follows in equation (10) and investigated versus variation of DRI/HBI % in EAF charge mix, 0.95% CaO in DRI/HBI, lime 78%CaO.

*Slag quantity, kg/t=(total lime, Kg*CaO%+EAF dolomite, Kg*0.6+0.95*DRI,Kg)/CaO% in slag/liquid steel,t*

(10)

The variation of slag weight with (DRI/HBI) % in EAF charge mix illustrated for 93 heat as in Fig.10 and may be given by the equation (11)

Slag quantity, kg /t =127+2.437 (DRI/HBI) % in EAF charge mix

(11)

It can be seen that 10% in (DRI/HBI) % in EAF charge mix leads to increase in slag weight by 24.3 kg.

The slag weight depends mainly on the content and composition of the gangue in direct reduced iron and the basicity of the slag [8]. So the slag weight increases as the DRI/HBI % in EAF charge mix increases.

3.3 Metallic yield and DRI /HBI percentage in EAF charge mix

Metallic yield of tapped steel during EAF operation steps also calculated and investigated versus variation of DRI/HBI % in EAF charge mix with 92.33% DRI/HBI metallization and it is found that metallic yield decreased from 92.6 to 84 .83% when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig.11.Decreasing of metallic yield with increasing DRI/HBI % is due to that increasing DRI/HBI quantity will result in increasing gangue quantity in the path which will be melted and moved up to the slag layer and hence metallic quantity will be also decreased. The obtained regression equation(12) as follows

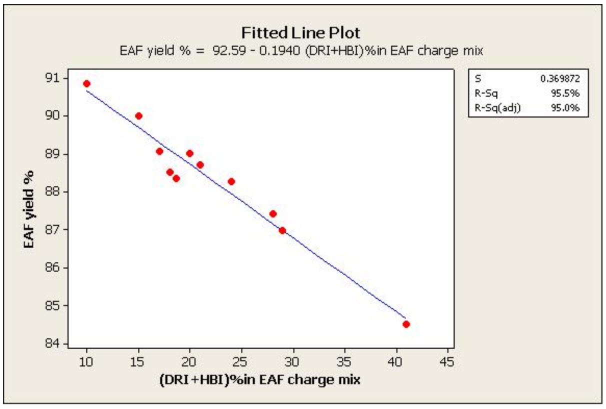

Fig. 11: Metallic yield in EAF operation vs. (DRI/HBI) % in EAF charge mix

Metallic yield %= 92.59 – 0.194 (DRI/HBI)% in EAF charge mix

(12)

3.4 Electric power consumption and DRI /HBI percentage in EAF charge mix

Electric power consumption, kWh per ton of tapped steel during EAF operation steps also calculated and investigated with 92.33% DRI/HBI metallization, 1.4% C versus variation of DRI/HBI % in EAF charge mix. It is found

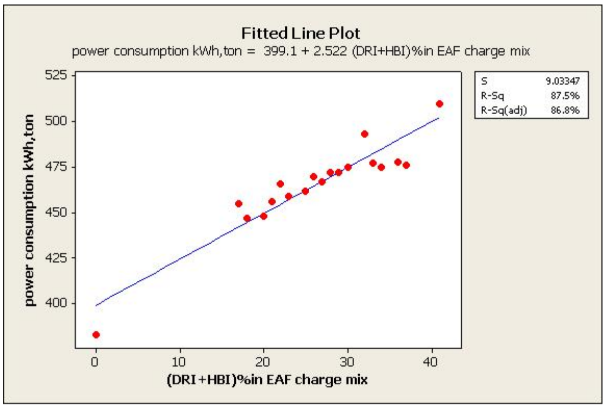

Fig. 12: EAF electric power consumption in EAF operation vs. (DRI/HBI) % in EAF charge mix

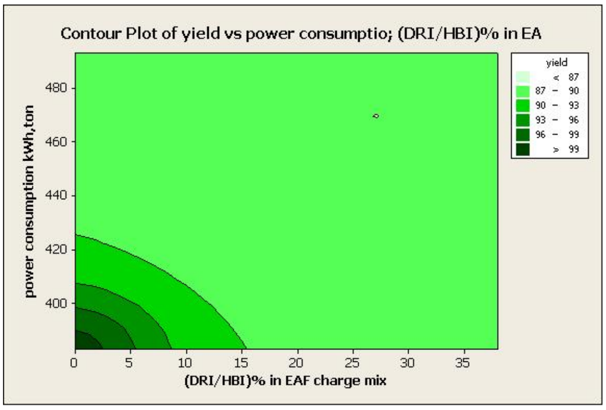

Fig. 13: Contour Plot of EAF Metallic yield vs. power consumption; (DRI/HBI) % in EAF charge mix

that electric power consumption increased from 399 to 500 kWh/t when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig.12. The obtained regression equation (13) as follows

Electric energy consumption, kWh/t = 399.1 + 2.52 (DRI/HBI) % in EAF charge mix

(13)

According to equation (13), an increase of 10% in (DRI/HBI) % leads to an increase in electric power consumption by 25kWh/t of liquid steel under the conditions of investigation.

The electric energy consumption 399 kWh/t which close to the data published by Marcus Kirschen [7] 390 kWh/t at 0% DRI .

Figure 13 shows that the increase in DRI/HBI is accompanied by increase in electric power consumption and decrease in EAF metallic yield. High power consumption due to DRI/HBI gangue content (4-5%).As a subsequent extra energy for melting would require melting the gangue materials [11]

3.5 Effect of DRI /HBI addition in EAF charge on power on time

Power on time taken during EAF operation steps (melting, DRI feeding and refining)for each heat recorded and investigated versus variation of DRI/HBI % in EAF charge mix and it is found that power on time increased from 48 to 56 minutes when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig.14. The regression equation (14) as follows

EAF power on time, min. = 48.17 + 0.1899 (DRI/HBI) % in EAF charge mix

(14)

The substitution of steel scrap with DRI increases the time needed for melting the EAF charge (Power-on time).This is attributed to the lower melting rate of DRI caused by the FeO that needs to be reduced. Moreover, having an acidic slag caused by the SiO2-, Al2O3-containing gangue materials in the DRI, it is also obvious that the specific consumption of lime and dolomite increases to manage the appropriate slag basicity near xCaO/xSiO2 = 2. Due to the increasing slag masses by increasing the DRI in metallic charge, one need again longer melting time to bring the slag into solution and accordingly need more electrical energy consumption[7].And this also the reason for increasing lime, total flux consumption and then slag quantity.

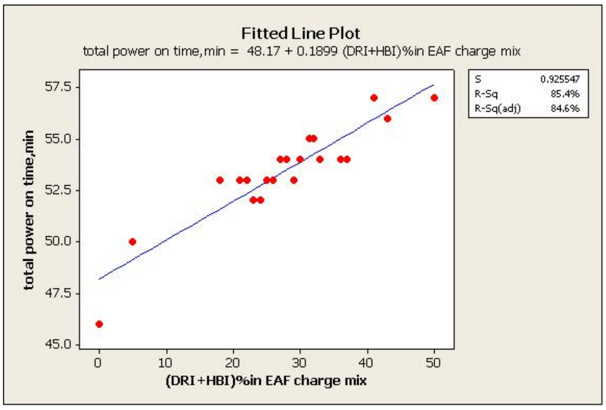

Fig. 14: EAF power on time EAF operation vs. (DRI/HBI) % in EAF charge mix

3.6 Total carbon consumption

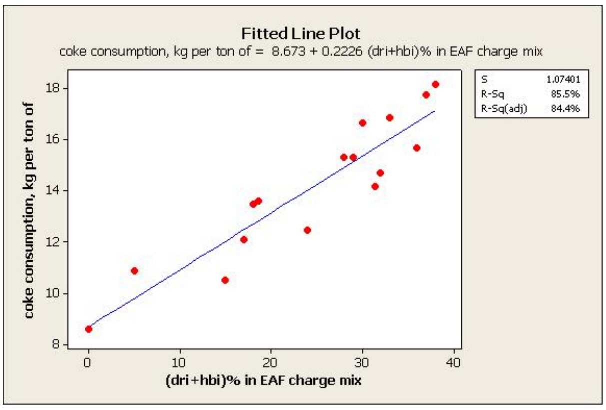

Fig. 15: Carbon consumption in EAF operation vs. (DRI/HBI) % in EAF charge mix

By investigating total carbon consumption (injected as carbon fines and added as lump coke) versus variation of DRI/HBI % in EAF charge mix. It is found that carbon consumption increased from 8.7 to 17 kg/t when (DRI/HBI) % in EAF charge mix increased from 0 to 40% as shown in Fig. 15. The obtained equation (15) as follows

Total carbon consumption, kg/t = 8.673 + 0.2226 (DRI/HBI) % in EAF charge mix

(15)

The obtained result 17 kg/t Total carbon consumption at 40% of (DRI/HBI) ,matched with data published by Marcus Kirschen [7] 17 kg/t for scrap based EAFs used in his investigation.

3.7 Total oxygen consumption versus DRI /HBI ratio in EAF charge mix

Oxygen consumption, Nm3per ton of tapped steel during EAF operation steps (melting, DRI feeding and refining) calculated and investigated versus variation of DRI/HBI % in EAF charge mix and illustrated as in Fig .16 and may be given by the equation (16)

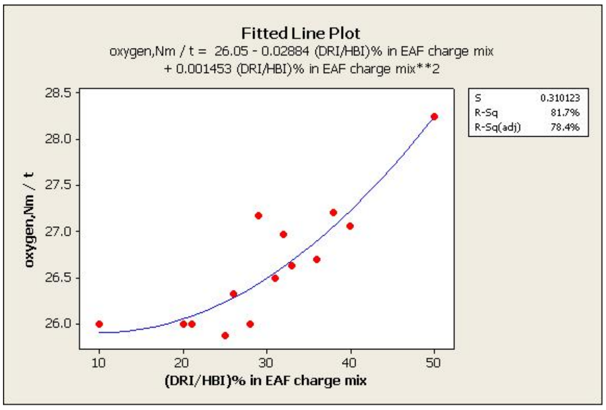

Fig. 16: Oxygen consumption in EAF operation vs. (DRI/HBI) % in EAF charge mix

*Oxygen, Nm / t = 26.05 - 0.02884 (DRI/HBI)% in EAF charge mix+ 0.001453 (DRI/HBI)% in EAF charge mix**2*

(16)

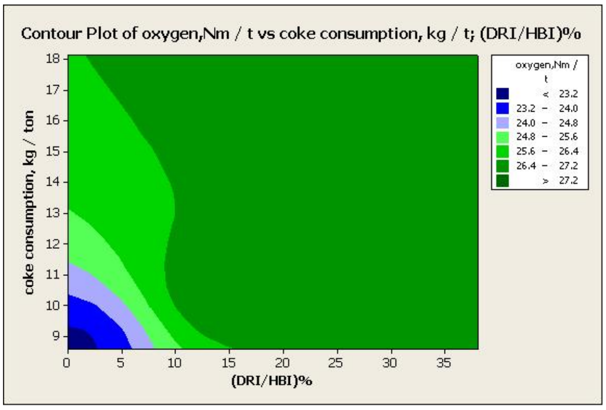

Fig. 17: Counter plot of coke consumption vs. oxygen consumption; (DRI/HBI) % in charge mix

It is seen that when DRI/HBI % in EAF charge mix increases from 0 to 40%, will result in increasing Oxygen consumption from 23.3 to 27.6 Nm3 /t. Increasing DRI/HBI will result in increasing the combustible carbon which will require more oxygen.

Figure 17 shows that the increase in DRI/HBI is accompanied by an increase in additional carbon and oxygen consumption, this explained as follows

Increasing DRI/HBI results in an increase FeO in EAF bath which requires more additional carbon to be reduced to metallic iron and hence more oxygen for foamy slag in EAF process [7].

3.8 Chemical energy and DRI /HBI ratio in EAF charge mix

Oxygen injection is a common practice in steelmaking; it is used to control the concentration of dissolved carbon in liquid steel and simultaneously to generate heat due to exothermic reactions [9].

$C + ½O = CO + 2.75KWh/Nm^3\ O_2$

$CO + ½O = CO_2 + 7KWh/Nm^3\ O_2$

$C + O2 = CO_2 + 4.88KWh/Nm^3\ O_2$

Other reactions in refining steps also produce chemical energy ,Chemical energy produced for each heat during EAF operation steps is recorded and calculated for ton of tapped steel and investigated versus variation of DRI/HBI % in EAF charge mix and it is found that chemical energy increased from 30 to 48.61 kWh /t when DRI/HBI % in EAF charge mix increased from 0 to 40% as shown in Fig.18.the obtained regression equation (17) as follows

Chemical energy, kWh/t = 30.48 + 0.2282 (DRI/HBI) % in EAF charge mix

(17)

It should be noted that the carbon produced in DRI (NG based) is usually more than the stoichiometric requirements needed to reduce the remaining portion of FeO in the product. DRI contains about 11 kgC/t_{DRI}. The excess carbon has significant impact on the FeO content of the slag and on the slag foaming that is required for an efficient EAF melting process [7].

In case of negative excess carbon, the necessary addition of coal for FeO reduction is beneficial when late in the EAF process [7].

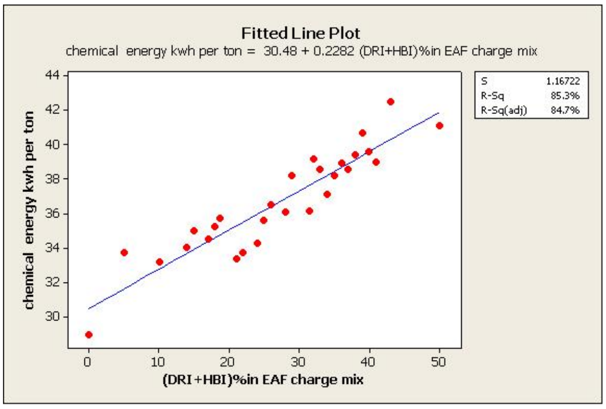

Fig. 18: EAF chemical energy vs. (DRI/HBI) % in EAF charge mix

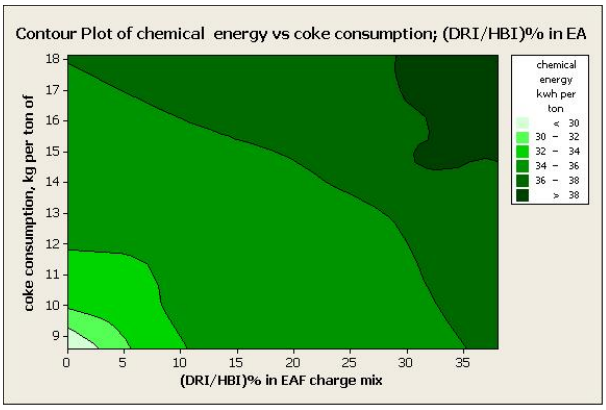

Fig. 19: Counter plot of Carbon consumption in EAF operation vs. chemical energy and (DRI/HBI) % in EAF charge mix

However, not all the iron oxide is reduced into Fe since a portion of the FeO does always exist in the furnace

slag. This means that the practical amount of excess carbon of DRI that is available for combustion in the steel bath, is more than the excess carbon calculated for DRI reduction. This term is called combustible carbon and defined as:

Combustible Carbon = xC, DRI −xC, stoichiometric (xFeO, DRI − xFeO, Slag) [7].

A second benefit obtained from the carbon in DRI is through the energetic benefits of Fe_3C. Fe_3C yields energy through the exothermic reactions obtained during its dissociation in the steel bath, -0.4 kWh/kgC, in contrast to endothermic dissolution of carbon particles in the steel bath, 0.62 kWh/kgC [7].

Figure 19 shows that an increase in DRI/HBI in EAF charge mix from 10 to 35% causes increasing in carbon consumption from 12 to 18 kg/t and consequently chemical energy increases from 32 to 34kwh/t.

The increase in DRI/HBI in EAF charge mix results in increase additional carbon which required for reduction the more FeO comes from DRI/HBI and consequently chemical energy increases.

3.9 Natural gas consumption and DRI /HBI ratio in EAF charge mix

Natural gas used with oxygen in EAF module burners which useful in scrap melting step.

Natural gas consumption, Nm^3/t of tapped steel during melting EAF operation step calculated and investigated versus variation of DRI/HBI % in EAF charge mix and illustrated in Fig. 20 and may be given by equation the equation (18).

It is shown that N.G consumption per ton of tapped steel Nm3/t decreased from 3.6 to 2.13 when DRI/HBI % in EAF charge mix increases from 0 to 40%. The consumed natural gas can be calculated from equation 19 as follows

N.G, Nm3 /t= 3.6 −0.03692 (DRI/HBI) % in EAF charge mix

(18)

3.10 Nitrogen content and DRI/HBI % in EAF charge mix

Nitrogen content in EAF samples investigated versus variation of DRI/HBI % in EAF charge mix, and illustrated in Fig.21.

It is found as a negative correlation which

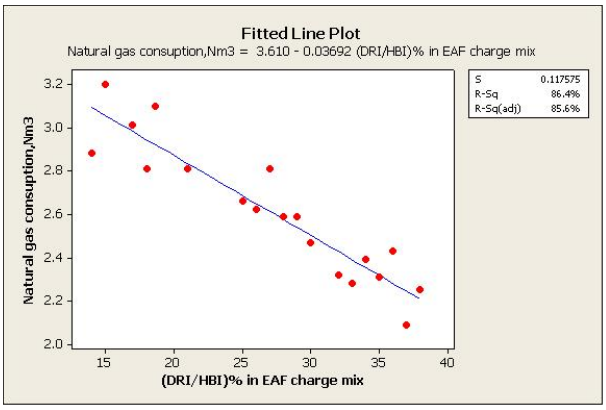

Fig. 20: Natural gas consumption in EAF operation vs. (DRI/HBI) % in EAF charge mix

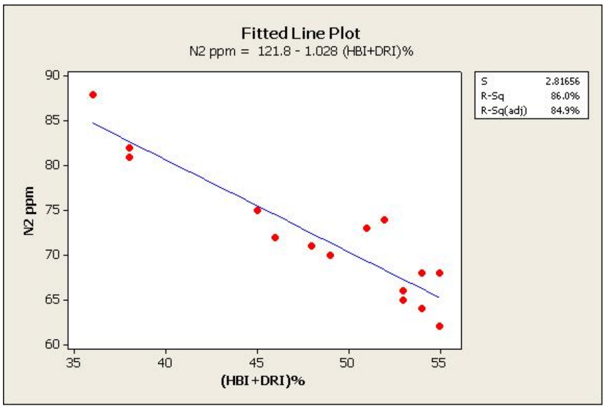

Fig. 21: Nitrogen % in EAF sample vs. (DRI/HBI) % in EAF charge mix

means decreasing in nitrogen content in EAF sample as DRI/HBI% in EAF charge mix increases as shown in Fig. 21

Nitrogen content in EAF sample can be calculated from the following obtained regression equation 19 as follows

$$\text{Nitrogen, ppm} = 121.8 - 1.028\ (\text{HBI/DRI})\%\ \text{in EAF charge mix} \tag{19}$$

The results agree with that obtained by Baosteel Group, Shanghai No. 5 Steel Co. Ltd. trial program. The results of the trials showed that nitrogen content decreased with increasing use of HBI [6].

The reason for decreasing nitrogen is that the combustible carbon reacts with the oxygen injected to the melt in the EAF, to release heat in the steel bath and also contribute CO gas in the slag foaming. With increasing combustible carbon in the EAF the nitrogen content of the tapped steel decreases.

Excess carbon from the DRI decreases the input of anthracite or injected graphite fines that is a major source for dissolved nitrogen in the EAF (0.1% N_2) besides infiltrated air [7].

3.11 Mechanical properties of hot rolled low carbon steel and DRI percentage in EAF charge mix

Tensile strength, yield strength and elongation percentage of 16 mm hot rolled low carbon steel rebar for 122 heats with variations from 13 to 33 DRI/HBI % in EAF charge mix also investigated and it is found that when DRI/HBI % increases, the yield strength decreases while the elongation percentage increases as shown in figure 22. Consequently the tensile strength decreases as sponge iron increases.

This may be a consequence of the low levels of residuals in the steels produced by using sponge iron. Similar results have been obtained by other authors. It has also been found that the low concentrations of residual metals and the low levels of nitrogen in the steels produced with high percentages of sponge iron make them coarse grained [8]

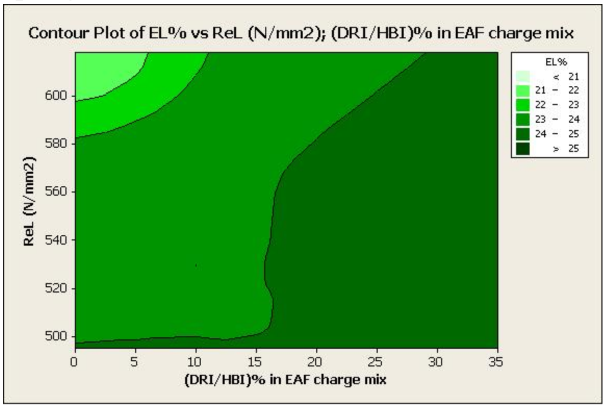

Fig. 22: elongation percentage of hot rolled low carbon steel, Yield strength vs. (DRI/HBI) % in EAF charge mix

This matched with the results obtained by Shanghai No. 5 HBI Trial Results shows that using HBI provides an improvement in toughness, elongation, reduction in area, and strength [6].

Regression equations (20), (21) and (22) for tensile strength, yield strength and elongation% are respectively

$$\text{Tensile strength } (\text{N/mm}^2) = 717.3 - 2.187\ (\text{DRI/HBI})\%\ \text{in EAF charge mix} \tag{20}$$

$$\text{ReL } (\text{N/mm}^2) = 460.6 - 1.247\ (\text{DRI/HBI})\ \%\ \text{in EAF charge mix} \tag{21}$$

$$\text{EL}\% = 16.06 + 0.1799\ (\text{DRI/HBI})\%\ \text{in EAF charge mix} \tag{22}$$

Abbreviations

Fig. : Figure
Kg/t: kilogram per ton of molten steel
Nm^3 /t: cubic meter per ton of molten steel
N.G: natural gas
Nm3/t : gas consumption per ton of tapped steel
min.: minutes
Wt%: weight percentage
kgC/tDRI: kilogram carbon per ton of DRI
TS(N/mm^2):Tensile strength ,Newton per square milimeter
ReL : Lower yield strength
El: Elongation

4. Conclusions

The effects of varying the direct reduced iron percentage in the electric arc furnace charge mix on important technological parameters have been investigated on a 185 ton electric arc furnace. Regression equations have been obtained; the following conclusions can be made:

1. Advantages increasing direct reduced iron in EAF metallic charge
   a- increasing percentage of DRI/HBI upon the bath residual metal level with medium quality scrap.
   b- Decrease significantly the content of copper, which is frequently associated with hot rolling difficulties and rolling mill yield losses, is decreased significantly. Beside that the other residual elements such as Ni, Sn

and Cr decreases

c- Increasing DRI/HBI to scrap can also result in a significant decrease in the input to the melting furnace of refinable impurities such as sulphur and phosphorus -The consumption of natural gas per ton of liquid steel decreases as percentage of direct reduced iron in EAF charge mix increases

d- Chemical energy increases as percentage of direct reduced iron in EAF charge mix increases

e- lowering contents of Nitrogen and hydrogen in produced steel.

f- The yield point and the tensile strength decrease slightly, whereas the elongation increases with growing direct reduced iron proportion.

g- increasing the productivity and saving energy in case of using hot DRI

h- The consumption of natural gas per ton of liquid steel decreases as percentage of direct reduced iron in EAF charge mix increases

2. Disadvantages increasing direct reduced iron in EAF metallic charge

a- Due to availability of scrap, direct reduced iron substitutes steel scrap but the increasing in DRI/HBI to scrap results in increasing the electrical power consumption beside consumptions of lime, fluxing material and carbon also.

b- The metallic yield decreases with increasing direct reduced iron proportion.

3. The slag weight per ton of steel, power on time and hence the tap-to-tap time of EAF increase with growing direct reduced iron proportion.
4. Increase DRI/HBI in EAF charge mix from 10 to 35% cause increase from 424 to 486 kwh/t but this increase can be lowered by about 10% of its value due to increasing carbon consumption by 6kg/t which accompanied by this direct reduced iron increase.
5. The positive and negative effects of using direct reduced iron on the steelmaking process require an optimization of both DRI/HBI in EAF Charge mix according to cost conditions.
6. Steel mills can benefit significantly from optimizing practices and logistics, increasing chemical energy use further and correctly using DRI/HBI percentage in EAF charge mix.

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