Case study on a new alternate charge material for electric arc furnace

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Introduction

Steel production through the electric arc furnace contributes nearly 30% of the total world steel production. To-day, this process is well established as an energy efficient economic process. The likely share of steel production through the electric arc furnace route is projected to go up to around 40% of the world steel production, by the turn of this century. Till the seventies, steel scrap has traditionally been used as a main metallic source, as it has certain advantages such as low power consumption, low slag volume, less wear in the refractory lining, besides smooth furnace operation. However, the presence of tramp elements in scrap has shortcomings in producing quality steel products. Besides the quality aspects, the phenomenal rise in steel production through the EAF and increasing adoption of continuous casting have had a great impact on the availability and cost of steel scrap.

It is in this context, that alternative metallic sources have been receiving due considerations from steel makers. The most common metallic inputs, apart from steel scrap, which are being used on commercial scale are :

- Direct reduced iron (DRI)
- Cold iron (pig iron)
- Hot metal

The physical properties of various alternative metallic sources are shown in Table-1. These materials are being used in varying degrees as a substitute for steel scrap. Materials have been used in varying degrees as a scrap substitute.

DRI has been found to replace steel scrap successfully to the extent of 100%, though the most preferred range is around 60-80%. However, DRI contains gangue as its inherent constituent, which cannot be eliminated by any reduction process. Presence of gangue constituent in DRI necessitates feeding more lime into the EAF in order to maintain the desired slag chemistry. This results in additional deslagging with substantial heat loss, operational delays, damage to refractory lining, prolonged melting time, higher power consumption, etc. However commercially, DRI has proved to be one of the most popular substitute for steel scrap especially in the developing countries.

Table-1 : Physical Properties of alternative metallic sources

Sl.	Property	Steel scrap	DRI	Iron carbide	Hot metal	Cold iron
I.	Bulk density	0.6-1.5 t/cu.m	2-3 t/cum.m	7.64 t/cu.m	6.7 t/cu.m (density) 1400°C, 4%C	3.5 t/cu.m constant value
II	Shape	1 meter is the limiting dimensions	Three basic shapes : - Pellet -Hot briquette (30x60x90mm) -Cold briqu-ette (3-20mm)	Beach sand sized	Liquid	Standard dimension as per IS:224: 45 kg-2notch (564 x 24 1x 83mm)22.5kg - inotch(600x 208x47mm)
III	Purity	Non-metallic materials may vary in the scrap (1% of non-metallic material cause a cost increase of around US$ 1.5/t of liquid steel)	Gangue material is 3-5.2% depending on -Type of process - Oe/pellet composition	Gangue material is 1.5-2% (can be separated as Fe_3C is strongly magnetic)	No non-metallic materials	No non-metallic materials
IV	Quality	Tramp elements viz. Si,Sb, Zn, etc. exceed 0.1-0.15% affecting product quality	Not tramp elements	No tramp elements	P is 0.25-0.35	Same as hot metal
V	Energy content	Practically negligible	Negligible	About 7% C in Fe_3C is source of latent energy	Sensible heat & oxidation of C, Si, etc. provide substantial amount of energy	C, Si & Mn are important sources of energy

Another alternate metallic source used in EAF's is basic grade pig iron. It contains high amount of silicon, manganese and phosphorus, due to which additional lime is required for adjusting slag basicity. As a result, slag generation is high. If plate iron pieces, which include sand layers trapped within it, is used, more lime consumption results.

Melting of cold iron is not significantly faster than that of heavy scrap of the same size. It can be charged only during the refining period, when substantial superheat of liquid metal is available. Scrap is initially melted and superheated to a certain level and then cold iron pieces are charged to avoid metal splashing.

The amount of cold iron that can be charged into the EAF, depends on the grade of steel being made. However, on an average, most carbon steel producers charge 13 to 23% cold iron in the charge-mix. Brazil is the only country where 30% pig iron is charged in EAF. It is reported that 30% pig iron in the charge-mix results in increased metallic yield and decreased energy consumption.

Use of hot metal in EAF is a relatively recent phenomenon. Hot metal with 'Carbon' and 'Silicon' dissolved in it, is a source of enormous heat on oxidation. This along with the sensible heat reduces power consumption substantially.

Hot metal does not contain gangue materials, as the latter is eliminated in the form of slag during the ironmaking process. However, removal of phosphorus and other metalloids present in the hot metal, calls for multiple slag practice, as lime is required to neutralize the oxidised products of metalloids.

Charging of hot metal into EAF is accomplished either through the roof or the slag door. In order to avoid problems of splashing of hot metal and excessive wear in the heath refractory lining, while charging hot metal through the roof, it is recommended to charge a basket of scrap in the beginning, melt down the scrap to a large extent and then pour the hot metal in the crater burned by the electrodes. In case of charging through the lag door, hot metal is poured through a refractory lined launder moving on rails.

Hot metal up to 50% has been successfully charged in EAFs. Charging more than 50% hot metal into EAFs results in operational problems, as excessive heat is produced by way of oxidation of carbon, manganese and silicon, which could overheat the EAFs, thereby jeopardizing the furnace operation. However, 30-40% hot metal charge is considered more suitable.

New alternate process

The recent announcement that NUCOR Steel Corporation has already started hot trials in the word's first full scale commercial scale iron carbide plant at Trinidad and Tobago, has made steel makers sit up and think, though the iron carbide process was initially conceived by Frank M. Stephens in the early 70's. The problems encountered by mini mills in recent years in obtaining economic alternatives to high quality scrap have generated a growing interest amongst steelmakers for this new alternative whose developers claim, will reduce the cost of steel making through the EAF.

Iron carbide is analogous to DRI having more than 6% carbon in the form of Fe_3C. It has a crystalline structure. It is made by a single step gas-solid reaction. Iron oxide (fine) is fed into a fluid bed reactor at a temperature ranging between 550°C and 600°C and a pressure of about 1.8 atm. Preheated process gas containing a mixture of carbon monoxide, carbon dioxide, methane, hydrogen and water vapour is introduced, which react with iron oxide to form iron carbide. The chemical reaction for the process is as follows :

$$3Fe_2O_3 + 5H_2 + 2CH_4 = 2Fe_3C + 9\,H_2O$$

The system for the production of iron carbide is shown schematically in Fig-1.

Extensive tests in the EAF were carried out by the North Star Steel and NUCOR steel in the United States. However, the iron carbide process for direct steel production either in basic oxygen convertors or in electric arc furnaces is owned by Iron Carbide Holding Ltd. USA.

Iron carbide contains lower amount of gangue materials as compared to DRI. Thus it requires lower amount of lime to maintain proper slag chemistry.

Iron carbide is introduced into molten steel by injecting it below the slag layer pneumatically using a lance. Because of its high melting point (1837°C), iron carbide does not melt directly. Instead, it dissolves in the molten steel bath thereby providing metallic iron.

Iron carbide contains 6-7% carbon. When carbon is burned with oxygen in the molten bath, large amount of heat is released. This reduces the need for equivalent amount of electric power. As a consequence, melting time is also reduced. In addition, foamy slag operation becomes easier, submerging the arc and improving thermal efficiency.

Large scale tests with iron carbide in commercial EAFs have confirmed that iron carbide is an ideal material for steelmaking because of its following properties:

- It has high carbon content of about 6-7% (Fe_3C)
- It has low sulphur content
- It is non-pyropheric material
- It can be injected into EAF
- Foamy slag practice is possible due to carbon boil
- It is low in residuals
- Furnace operation requires lower power consumption

While sufficient experience has not been acquired to quantify the effect, it is expected that the use of iron carbide in EAF steelmaking will reduce the consumption of electrodes and maintenance of the furnace in general. Concerns expressed that the finely divided iron carbide powder could be swept away with the furnace off-gas resulting in poor recoveries, have been nullified during large commercial scale tests demonstrating excellent recovery of iron units. Further, it is claimed to be environment friendly.

Case study under Indian conditions

For evaluating the use of alternate iron sources in the Indian context, it would be worthwhile to first examine the status and performance of Indian mini steel plants and then evolve a model plant on the basis of which an analysis could be carried out.

The status and performance of Indian mini steel plants

The electric furnace based mini steel plants in the country account for a significant share of the country's total steel production. Presently, the total number of mini steel plants installed in the country stands at 177. Region-wise break-up of the number of mini steel plants in the country is as follows :

- Eastern region = 33 Nos.
- Northern region = 62 Nos.
- Southern region = 30 Nos.
- Western region = 52 Nos.

177 Nos.

The present installed capacity of the mini steel plants in the country is around 7.3 Million Tonnes per year. In the year 1991-92, the mini steel plants contributed 21.4% of the total Indian steel production (3.35 MT out of total 15.6 MT).

The Indian mini steel industry depends primarily on steel scrap as feed material. Non-availability, poor quality and fluctuating price of steel scrap, however, hinder steel production in mini steel sector. The mini steel industry in the country has to resort to large scale import of melting scrap. The industry has, therefore, attempted replacement of scrap, partly by alternate iron bearing material, primarily DRI.

Model plant for case study of alternate iron sources in EAF

In order to assess the impact of use of alternate iron bearing materials, a model plant has been evolved with the following facilities and assumptions :

No. and size of EAF	:	1 x 45 t/36 MVA Transformer
Ladle Furnace	:	1 x 45 t/8 MVA Transformer

Features incorporated :

- Bottom tapping system
- Water cooled panels and roof
- Water cooled electrodes
- Emission control system
- Oxy-assisted melting/refining
- Process automation

Further downstream facilities could either consist of a single strand slab caster and a steckel mill to roll HR coils or one number, six strand billet caster along with bar & rod mill of appropriate capacity to produce non-flat products.

Alternative charge-mix

The following five alternatives with different composition of metallic charge-mix have been considered for the purpose of present analysis :

Alternative I	:	100% Scrap
Alternative II	:	50% Iron carbide & 50% scrap
Alternative III	:	40% Hot metal & 60% scrap
Alternative IV	:	70% Scrap & 30% cold iron
Alternative V	:	80% DRI & 20% scrap

In case of an Alternative V, two options have been considered

Option I	:	With captive DRI plant
Option II	:	With purchased DRI

Techno-economic comparison

In order to carry out a techno-economic comparison, the indicative order of investment, works cost and the total production cost have been calculated and compared at the liquid steel stage. The costs for downstream facilities have not been considered, as they are common to all the alternatives. The total production cost of steel clearly reveals the cost effectiveness of using various alternate charge materials based on different type and usage of input materials as well as energy input required.

Of the various alternate iron sources considered above, scrap, DRI and cold iron are freely traded in the international as well as domestic market. Their prices are available and have been taken into account. However, DRI would also be produced within the plant, in which case additional investment could be required for installation of two DR nodules of 100,000 t/yr capacity each.

Hot metal perforce, has to come from an adjoining ironmaking unit located close-by to the electric arc furnace shop. In this alternative (Alt-III), a 350 m^3 blast furnace is envisaged for which appropriate investment has been accounted.

Iron carbide is presently not produced anywhere in the world. A full scale commercial plant, however, is slated for operation in 1994. It is unlikely that iron carbide would be freely available in the market for steelmaking, unless more such plants come up and the technology is mastered. The iron carbide plant is presently available in module size of capacity 330,000 t/yr. The specific investment figure reported for setting up such iron carbide modules is approximately US $ 110-120 per tonne of installed capacity. However, the investment may vary under Indian condition.

Therefore, in the alternative using iron carbide, it is assumed that iron carbide plant would be set up in India based on use of natural gas. The most logical site for installation of iron carbide plant would be on the west coast or along the HBI gas pipeline. In addition, Godavari basin could also be a potential area for setting up such plants, once natural gas is available there.

Based on available information, production cost of iron carbide excluding depreciation and interest charges works out to Rs 2775/t. Taking into account the capital related charges, profit margin and transportation/handling costs, the landed cost of iron carbide works out to Rs 4150/t and has been adopted for the present exercise.

Besides the above assumptions, the comparative economics of various alternatives would hinge on the sourcing/pricing as well as usage of major input materials including metallic charge-mix. The usage norms as adopted for major input materials under all the alternatives considered are as follows :

Usage norms considered for major input materials

Item	Unit	Alt.I100% scrap)	Alt.II(50% Fe_3C & 50% scrap)	Alt.II(40% hot metal % 60% scrap)	Alt.IV(70% scrap & 30% cold iron)	Alt. V(80% DRI & 20% scrap)
1. Steel scrap	kg	1055	550	665	760	215
2. Iron carbide	kg	-	590	-	-	-
3. Hot metal	kg	-	-	445	-	-
4. Cold iron	kg	-	-	-	325	-
5. DRI/HBI	kg	-	-	-	-	915
6. Lime	kg	25	33	50	40	55
7. Electricity	kWh	450	425	300	430	650
8. Oxygen	Nm^3	20	54	35	30	17
9. Electrode	kg	4.0	3.9	3.0	3.9	4.6

Major plant facilities, liquid steel production, order of capital cost, production cost of liquid steel as well as relative order of ranking for all the alternatives as discussed above are furnished at Table-2. As can be observed from this table, steelmaking through EAF using iron carbide to the extent of 50% in the metallic charge-mix emerges techno-economically, as the most effective process.

In carrying out the above comparison, the landed price of purchased metallics inputs, lump ore, fluxes and additives, based on prevailing market prices and as assumed for the current exercise are given below :

Steel scrap	Rs 6,300/t
DRI/HBI	Rs 6,000/t
Cold iron	Rs 6,500/t
Lump iron ore	Rs 600/t
Lime	Rs 2,000/t
Coke breeze	Rs 2,000/t

Power requirement for the plant envisaged under various alternatives has been assumed to be met through purchase from the state utility grade @ Rs 2.0 kWh.

Conclusion

The preceding paragraph on techno-economic comparison reveals that iron carbide holds a promising potential as a cost-effective substitute given the present price scenario of scrap, sponge iron and power tariff. The above comparison is very much sensitive to the movement of international as well as domestic price of scrap, which in turn affects the price of DRI/HBI in the Indian market. It may be seen that in alternative-III, power consumption is minimum. Use of hot metal would be comparatively more profitable, once the power tariff further goes up, which is very likely in the near future.

However, much would depend on the technology aspects of setting up iron carbide plant and the investment which this would entail. In the ultimate analysis, the price at which iron carbide can be made available to the steelmakers, would determine its use in future.

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Table-2 : Techno-economic comparison for various alternatives

Sl. No.	Alternatives / Items	Alt-I (100% scrap)	Alt-II (50% iron carbide 50% scrap)	Alt-III (40% Hot Metal & 60% scrap)	Alt-IV (70% scrap & 30% cold iron	Alt-V (80% DRI, 20% scrap) Option-I Own DRI	Option-II Pur. DRI
I	Liquid steel capacity t/yr	255000	220000	280000	200000	200000	20000
II	Major plant facilities						
1.	Blast furnace comple	-	-	1x350cu.m	-	-	-
2.	DR plant(Coal based)	-	-	-	-	2x0.1Mtpy	-
3.	EAF plant incl LF	1x45t	1x45t	1x45t	1x45t	1x45t	1x45t
III	Indicative order of investment(Rs crores at 1994 prices)	50	50	170	50	250	50
IV	Production cost of Liquid steel (Rs/t)						
1.	Works cost	9100	8475	8325	9375	6900	9850
2.	Capital related charges	400	450	900	450	2500	500
	Total production cost	**9500**	**8925**	**9225**	**9825**	**9400**	**10350**
V	Order of ranking	IV	I	II	V	III	VI

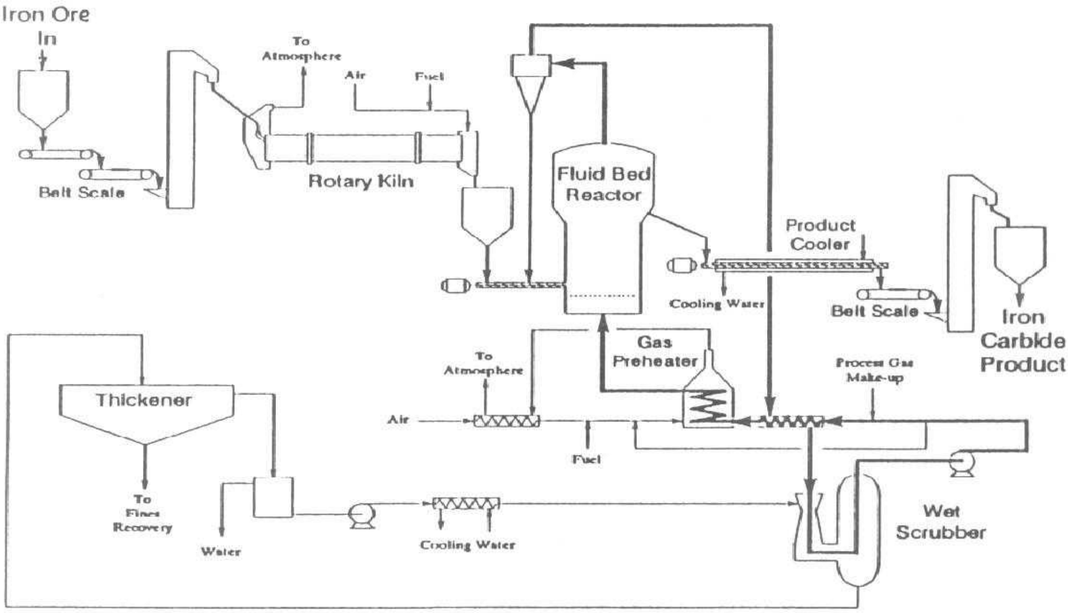

Fig.1 : Simplified Flow Diagram of the iron carbide process