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Mini Review

# Supplements of Scrap in Steelmaking

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## Abstract

Steel scrap is an important raw material for electric steel making. The advent of continuous casting, which accounts 96.6% of the world crude steel output, has reduced drastically internal scrap generation in steel plants. The non-availability of consistent quality at a reasonable price necessitated the search for an alternative to scrap for use in steelmaking. These problems have been overcome with the help of i) sponge iron/DRI which is product of DR processes; ii) hot metal which can be produce by alternate routes of ironmaking. Sponge iron/DRI is not only a substitute for steel scrap as a feed material in EAF/IMF, but also a more suitable melting stock for the good quality steel production. Sponge iron/DRI derived from virgin iron units is a relatively pure material which dilutes contaminants in the scrap and improves the steel quality. Sponge iron/DRI offers consistency in composition and size, low residual elements and environment friendliness. The purpose of alternate smelting reduction is to produce hot metal similar to the blast furnace hot metal but without any depending on metallurgical coke. Hot metal, produce from alternate ironmaking processes, can be charged to EAF/IMF (within plant) to reduce scrap as well as electric power consumption.

**Abbreviations:** HBI: Hot Briquetted Iron; EAF: Electric Arc Furnace; IMF: Induction Melting Furnace; DRI: Direct Reduced Iron; SR: Smelting Reduction

## Introduction

Steel is the main driving force of economic progress of any country. World steel production increased to 1868.8 million tonne (Mt) in 2019 from 1813.6 Mt (in 2018) [1]. The steel industry in India is jump in world steel production from 101.5 Mt in 2017 (occupied 3rd position in World) [2] to 111.2 Mt in 2019 (maintained 2nd position in World). By producing 109.3 Mt steel in 2018, India occupied 2nd position in the world's steel production [1]. At such a juncture, mindless production boom sans any concern for the environment can ruffle the steel scenario. The world steel production is mostly shared by two processes, namely, oxygen steel making and electric furnace (in a ratio of 71.9:27.7). The consumption of scrap is about 900 kg from a total metallic charge of roughly 1080 kg for producing one tonne of liquid steel through electric arc furnaces. In oxygen steel making, about 20 to 25% of the charge is scrap which act as coolant. The advent of continuous casting, which accounts 96.6% of the world and 87.1% Indian crude steel output1, has reduced drastically internal scrap generation in steel plants. The non-availability of consistent quality at a reasonable price necessitated the search for an alternative to scrap for use in secondary steel sectors throughout the world. These problems have been overcome with the help of sponge iron/Hot Briquetted Iron (HBI). Sponge iron/HBI is not only a substitute for steel scrap as a feed material in Electric Arc Furnace (EAF)/Induction Melting Furnace (IMF), but also a more suitable melting stock for the good quality steel production. It is evident that sponge iron/HBI is influence the supply and demand balance for steel scrap because electric furnace operators regard it as a high-quality substitute for scrap. Sponge iron/HBI is now recognized as a high quality, cheaper and high purity charge material on the world over. In comparison with scrap, the use of sponge iron/HBI offers consistency in composition and size, low residual elements and environment friendliness.

## 1. Sponge Iron

Sponge iron means porous iron produced by direct reduction (DR) process. This is a solid-state reaction process (i.e. solid-solid or solid-gas reaction) by which removable oxygen is removed from the iron ore, using coal or reformed natural gas as reductants, below the melting and fusion point of the lump ore or agglomerates of fine ore [3]. The external shape of the ore remains unchanged. Due to removal of oxygen, there is about 27 to 30% reduction in weight, a honey combed microstructure remains which have suggested the name Sponge Iron (means solid porous iron, lumps/pellets, with many voids filled with air). It is also known as Direct Reduced Iron (DRI). The direct reduction processes have some basic advantages as follows [3]:

a) They are easily adaptable to small as well as moderately large size steelmaking units,
b) Their capital cost requirement is low,
c) They can work with off grade raw materials,
d) They can utilize small sources of iron ore near the steel plants, thus reducing transportation cost,
e) Their products are uniform in size, as well as they contain low levels of tramp metallic elements (0.02%) compare to scrap (0.13-0.73%).

Direct reduction (DR) processes are very sensitive to chemical and physical characteristics of raw materials used in the process. Iron ore or pellets, reductant (i.e. non-coking coal or natural gas) and limestone/dolomite are the main raw materials for DR technology. For the successful operations, the process of DR technology has specified the characteristics of the raw materials to be used in the process. Flow diagram of DR processes is shown in Figure 1.

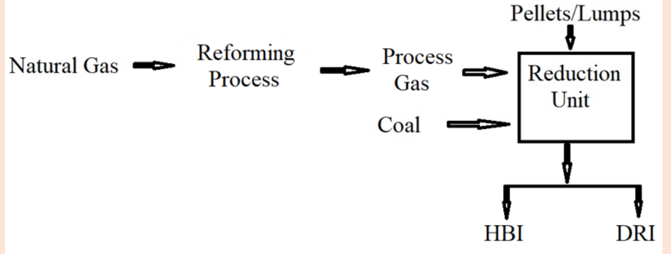


**Figure 1:** Flow diagram of DR processes.

Based on the types of reductant used, the DR processes can be broadly classified into two groups:

1. Using solid reductant i.e. Coal-based Direct Reduction (DR) Processes, and
2. Using gaseous reductant i.e. Gas-based Direct Reduction (DR) Processes.

a) DR processes are summarized as shown in Table 1.

**Table 1:** DR processes [4].

| Process | Type of Reactor | Type of Ore Use | Type of Reductant | Rank* |
|---|---|---|---|---|
| MIDREX | Shaft | Lump/Pellet | Gaseous | 1 |
| HyL | Retort/Shaft | -do- | -do- | 3 |
| SL/RN, ACCAR, CODIR etc. | Rotary Kiln | -do- | Solid | 2 |
| HIB | Fluidized Bed | Fine | Gaseous | 4 |

*Rank is in terms of popularity and production in the world.

Sponge iron is consumed in three primary product forms namely lump, pellets and hot briquettes. The other secondary product form is cold briquettes made from sponge iron fines. Hot briquettes form is popularly known as hot briquetted iron (HBI). HBI is a combined solid form of sponge iron lump and pellets, hot pressed at 700 to 800 °C, immediately after its production in gas-based processes. HBI °C an be produced only from gas-based processes. HBI cannot be produced from coal-based processes, due to present of coal ash and unburnt coal with sponge iron in the product.

### 1.1 Uses of Sponge Iron/HBI

Due to shortage of scrap in 1980s, sponge iron/HBI is used as feed materials in steelmaking. Sponge iron/HBI act as burden enrichment in BF, as a coolant in LD/BOF and as a charge material for EAF/IMF. The quality steel contains total summation of carbon, sulphur, nitrogen and hydrogen would be 100 to 150 ppm (i.e. 0.01 to 0.015%), by using sponge iron/HBI as feed materials in EAF that can be achieved. The advantages of sponge iron/HBI as a feed material can be summarized as follows [4]:

a) Known and uniform chemical composition,
b) Uniform size, capability of continuous charging;
c) Very low levels (0.02%) of residual elements (like Cu, Sn, Ni, Cr, Mo etc.), whereas scrap and pig iron contain 0.13 to 0.73% and 0.06% residual element respectively;
d) Diluting the residual elements in steelmaking,
e) Maintenance of low levels sulphur,
f) Unreduced iron oxide in sponge iron/HBI reacts vigorously with carbon in molten bath (carbon boil), that improves heat transfer, slag metal mixing, homogeneity and low content of dissolved gases of the bath;
g) Capability of forming protective cover of the arc by foamy slag in the EAF bath,
h) Potential of sensible heat recovery from waste gases,
i) Sponge iron/HBI has a predictable price structure than scrap. Since sponge iron/HBI is a product and scrap is a byproduct.

### 1.2 Oxygen Steelmaking

Sponge iron is also being charged in LD/BOF steelmaking as coolant. HBI is the form of sponge iron best suited for use in the LD/BOF because of its bulk density and physical strength. Sponge iron with lower degree of metallization has more cooling effect. The use of sponge iron has yielded better results compared to scrap cooling. If scrap gives 1.0 unit of cooling effect, sponge iron gives 1.2 units of cooling effect, i.e. it is 20% more efficient [5]. Relative to scrap, the cooling effect of HBI is higher due to higher heat of fusion (394 kJ/kg) than scrap (298 kJ/kg).

### 1.3 Electric Steelmaking Furnaces

Batch charging sponge iron/HBI above 20 to 35% of the total metallic charge generally has a negative effect on productivity. Sponge iron/HBI can be charged continuously due to uniform sizes. Up to 25% sponge iron/HBI can be charged with the scrap, more can be added through the roof of the furnace by continuous feeding mode. The productivity of an EAF, continuously fed sponge iron/HBI, is largely dependent on consistent sponge iron/HBI chemistry, slag foaming and good control of the sponge iron/HBI feed rate. EAF productivity will be negatively affected if a ferro-berg forms (i.e. sponge iron float above the slag level just like ice-berg float in Atlantic Ocean) due to over-feeding of the sponge iron/HBI. Probability of ferro-berg formations are more for sponge iron than HBI, due to lighter density of sponge iron. Since HBI is denser than sponge iron, HBI sinks to the bath; sponge iron floats to the slag-metal interface. Sponge iron/HBI is utilized as a scrap replacement and diluting of the residual elements containing in scrap. Obviously, residual levels will drop as the sponge iron/HBI percentage increases but of equal importance, nitrogen levels show a similar reduction with proper slag foaming. Many factors tend to increase energy consumption when melting sponge iron/HBI. Sponge iron/HBI metallization affects energy consumption. The lower the metallization, the higher the FeO level in sponge iron/HBI. Chemical reduction of FeO is an endothermic reaction:

$$FeO\ (s) + C\ (s) = Fe\ (s) + CO\ (g),\ \Delta H^0_{298} = 153.9\ kJ/mol\ of\ C$$

Reduction of one tonne of FeO to Fe will require around 800 kWh at steelmaking temperatures [6]. 1% C is required to balance out 6% FeO in sponge iron/HBI. Hence steelmaker always prefer higher carbon content in sponge iron/HBI. All gangue elements of the iron ore remain in the sponge iron/HBI and need to be separated via the slag in the EAF. This increases the electrical energy and electrode consumption of the EAF compared to steel scrap melting. This energy consumption can be reduced by immediate transfer of hot sponge iron/HDRI to the EAF melt shop. The use of sponge iron/HBI as a charge material has increased substantially with increasing world sponge iron/HBI production to 100.49 Mt in 2018 [7]. In recent years most of the captive sponge iron/HBI production units installed have been focused on charging of hot sponge iron (HDRI)/HBI to the EAF at temperatures in the range of 600 °C. Most of the world sponge iron/HBI productions are gas-based reduction processes (79.7%) but a small fraction is produced using coal-based processes (20.2%). Charging hot sponge iron (HDRI)/HBI is possible only for gas-based processes but oxidation is a problem. Transporting hot sponge iron (HDRI)/HBI directly from the module must be done under a sealed nitrogen or process gas atmosphere before charging to the EAF. Charging hot sponge iron (HDRI)/HBI at temperatures up to 600 °C rather than cold sponge iron (HDRI)/HBI results in a melting energy reduction of 150 kWh/t of crude steel (>0.5 GJ/t) [8]. The products of coal-based processes are not possible for hot charging due to present of coal ash and unburnt coal with sponge iron.

There are two primary benefits of charging hot sponge iron (HDRI) at 600-650 °C into an EAF i) lower specific electric power consumption and ii) increased productivity (15-20% or higher). The energy savings occur because less energy input is required to heat the sponge iron to melting temperature, which results in a shorter overall melting cycle. The rule-of-thumb is that electric power consumption can be reduced about 20 kWh/t liquid steel for each 100 °C increase in sponge iron charging temperature. Thus, the savings when charging at over 600 °C can be 120 to 140 kWh/t liquid steel [9]. An additional benefit of a shorter overall melting cycle is a reduction in electrode (at least 0.5-0.6 kg/t liquid steel) and refractory consumption (at least 1.8-2.0 kg/t liquid steel).

## 2. Hot Metal

Due to shortage of metallurgical coke, smelting reduction (SR) processes are developed for hot metal production. All smelting reduction processes aim to produce hot metal, without using either metallurgical coke or high-grade iron ore as the feedstock. The smelting reduction processes deserve special attention since they use non-coking coal for production of hot metal. Apart from smelting reduction processes, other alternate ironmaking processes are also produced hot metal:

a) Low shaft furnace i.e. mini-BF, in which the strength of ore or coke is not so important, non-metallurgical coal can be used as a fuel;
b) Charcoal BF, using charcoal as a fuel;
c) Submerged electric arc furnace, using poor quality of coke as reducing agent and thermal requirement of the process to be met by electrical energy,
d) Rotary hearth furnace, using iron ore-coal composite pellets. The iron ore and non-coking coal fines are used to form green composite pellets or briquettes. Direct use of coal as reducing agent in the composite. Reduction rate is very fast, so productivity is high. The heat requirement for furnace is met through firing of gases.

### 2.1 Uses of Hot Metal

Since hot metal contains very good chemical potential due to present of impurities (e.g. C, Si, Mn etc.) content, during refining a lot of heat generated due to heat of oxidation. Hot metal, produce from alternate ironmaking processes, can be transported and charged to an adjacent EAF/IMF (within plant) to reduce electric power consumption.

## Summarization

Steel scrap is an important metallic feed material for electric steel making (EAF/ IMF) which constitutes 28% of the world steel production. The non-availability of consistent quality at a reasonable price necessitated the search for an alternative to scrap for mainly use in secondary steel sectors. Although steel scrap is rather a tailor-made input material, problems faced by steelmakers are its short supply, fluctuating prices, heterogeneous nature and above all higher content of residual elements. The non-availability of consistent quality scrap at a reasonable price necessitated the search for an alternative to scrap for use in secondary steel sectors. This problem has been tackled using sponge iron/HBI which is not only a substitute for steel scrap as a feed material in EAF/ IMF but also a more suitable melting stock to produce good quality steels.

## Conclusion

Smelting reduction is an alternative approach to iron making which uses non-coking coal to reduce iron ore in the forms of lump ore, pellets or fines to molten iron. It is the only alternative to the blast furnace. The purpose of smelting reduction is to produce liquid hot metal similar to the blast furnace but without any dependency on coke. Hot metal, produce from alternate ironmaking processes, can be charged to an adjacent EAF/ IMF (within plant) to reduce scrap as well as electric power consumption.

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