UPGRADATION OF LOW GRADE IRON ORE FOR IRONMAKING

Executive Summary submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

In

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By

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RESEARCH METHODOLOGY

Identification of research problem:

Iron ore deposits are finite, non-renewable and irreplaceable natural resources and with fast depletion of high grade iron ore; conservation of iron becomes our prime focus area to increase mine life. India has huge reserve of iron ore out of which 35 pct of reserve is low-grade iron ore at present. Additionally, Indian iron ore deposits are partly soft and friable in nature. Mechanized mining, mineral processing and beneficiation operations result in generation of fines which accounting for around 70 pct of the total production of the country's iron ore. Simultaneously, Coal is an important raw material of steel sector having an issue like limited sources of coking coal and huge amount of inferior quality of non-coking coal.

India is a second largest producer of steel in world since 2018. Iron and steel industry's growth in India has been recorded exceptional in the past and present decade. The industrial development programme of any country is based on its natural resources. Natural resources are depleting due to its high demand. To meet demand of steel industry, beneficiation of low-grade iron ore can be one of solution. Iron ore resource has its own peculiar mineral characteristics requiring suitable beneficiation process to produce quality raw material. Mineralogical studies have become an integral part of mineral processing and beneficiation of an ore. Mineralogical studies are helpful to be familiar with the nature of association of gangue with the ore. In mineralogical studies, characterization techniques are such as Fluorescence Spectrometer (XRF), X-Ray Diffractometer (XRD), Scanning Electron Microscopy (SEM) and Energy Disperse Spectroscopy (EDS), helpful to determine different phases by qualitatively and quantitatively as well as their morphologies. The role of characterization studies is a vital to propose and design a process flow sheet for low-grade ores.

Beneficiated iron ore are available in fine size only which can be used as agglomerates. Cold bonded composite briquettes / pellets can use iron ore and coal fines. In last two decades, composite agglomerates are getting popular due to its advantages like: fast reduction rate, consistent product quality and pollution control by using fines. By incorporating non-coking coal fines or coke breezes with up-gradated iron ore in cold bonded iron ore-coke/coal composite pellets which can be reduced the metallurgical coke requirement in the blast furnace. Due to scarcity of good quality iron ore and coking coal, smelting reduction (SR) processes are alternative of blast furnace ironmaking/steelmaking. Smelting reduction process has flexibility in quality and grades of raw materials. Such process can be set up at small scale level which can't be feasible in BF ironmaking. . The purpose of SR process is to produce liquid hot metal similar to the blast furnace hot metal but without any dependency of coke. It requires a minute preparation of iron oxide feed and uses coal, oxygen and/or electric energy.

One of source of iron is scrap which usage in India is low because of non-availability of quality scrap. Many steel producers using electric arc furnace (EAF) which prefer hot metal over scrap due to high power tariff. Import of good quality scrap is expensive and which can meet only a small share of national requirement. Scrap arising within steel plant (*home scrap*) is not adequate to meet the full requirement. It is therefore, necessary to increase part of iron bearing charge materials in steelmaking.

Objective of research work:

Looking into the above aspect, the objective of present study is twofold:

1. Mineralogical and beneficiation studies of low-grade iron ore by using several techniques and constructing an appropriate route for beneficiation with good recovery of iron and upgrading the iron content.
2. Utilization of composite briquettes in liquid metal bath for steel making. As well as auxiliary studies as backup investigation with emphasis on isothermal reduction kinetics.

Research Methodology for present work

In present study, an attempt was made to utilize low-grade iron ore for ironmaking/steelmaking. Literature study consists of the Indian low-grade iron ore and broadly reviews on beneficiation of it. It discusses the impact of mineralogical studies on beneficiation studies. Further it covers cold bonded composite agglomeration and smelting reduction technologies for ironmaking/steelmaking.

Experimental work is sequenced as below:

I. Mineralogical studies of low-grade iron ore
II. Beneficiation studies of low-grade iron ore by using several techniques
III. Different size of composite briquettes making and testing of composite briquettes
IV. Reduction studies (isothermal and non-isothermal) of composite briquettes and characterization of isothermal composite briquettes
V. Utilization of composite briquettes in liquid metallic bath for steel making.
VI. Testing of produced steel samples

For these studies of raw materials, iron ores were collected from mines of (i) Bonai ranges of Jharkhand - Odisha sector and (ii) Red and Yellow ochre from Bhilwara – Rajasthan state. Charcoal and coke were procured from local market of Vadodara and Rajkot respectively.

I. Mineralogical studies of low-grade iron ore

Initially, mineralogical studies were carried out to gather the information related to mineral phases which have been helpful in beneficiation studies. Following analysis / test of raw materials were carried out in sequence.

- Megascopic studies of ores
- Hardness of ore by Mohs scale
- Density of ore
- Ore microscopy – *Phase identification, texture, Size measurement*.
  a) Polarized microscope

b) Reflected (Stereo and Conventional)

- Phase identification (by XRD)
- SEM & EDS Analysis - Surface morphology and topography.
- Chemical analysis of iron ore (by XRF)
- Proximate analysis of coal/coke

II. Beneficiation studies of low-grade iron ore by using several techniques

Two different types of low-grade iron ore: Odisha (BHQ) and Rajasthan (Goethite) were taken to beneficiate. Odisha and Rajasthan iron ore crushed and grinded as per the requirement of beneficiation methods. Chemical analysis of iron ore were carried out on each process steps. Proximate analysis of coke and charcoal were carried out for presence of constituents.

Odisha ore: Different sized ore were beneficiated using various methods like jigging, Wilfley table (Tabling), air classifier and hydraulic classifier. After beneficiation trials, the two methods were finalised. Odisha Ore is upgraded with iron recovery of 59.75 pct.

Rajasthan ore: Magnetic roasting process was applied to upgrade a lean grade ore. Several trials were taken with different parameters (particle size of ore, time and temperature). Magnetic roasting was carried out with two different carbonaceous materials like coke fines and charcoal fines for stoichiometric reactions. OOre is upgraded with recovery of about 90 pct by both carbonaceous materials.

III. Different size of composite briquettes making and testing of composite briquettes

Based on combination of ore and carbonaceous materials; four type of composite briquette is prepared from Rajasthan ore and coke / charcoal. Two different sized composite briquettes were prepared: (a) for isothermal reduction studies and (b) for smelting reduction studies. Drop test, Compressive strength and shatter index were measured of composite briquette.

IV. Reduction studies (isothermal and non-isothermal) of composite briquettes and characterization of isothermal composite briquettes

Isothermal and non-isothermal studies are carried out for Rajasthan ore with pre-decided variables. Tube furnace was constructed for isothermal reduction studies. **(Refer figure 1)** The variables for smelting reduction of composite briquettes are shown in **Table 1**. Degree of reduction and activation energies was calculated. SEM and XRD analyses are carried out to identify phases generated or transformed during reduction process. TG-DTA technique was applied for non-isothermal studies under specific conditions. Activation energies were calculated from TG-DTA curve.

Figure 1: Tube Furnace

Table 1: Variable for isothermal reduction of composite briquettes

Sr. No.	Variable	Number
1	Iron ore	2
2	Carbonaceous material	2
3	Temperature, T (K)	3
4	Time, t (s)	5

V. Utilization of composite briquettes in liquid metallic bath for steel making.

Smelting reduction studies are employed to extract iron from iron ore. These studies were carried out at laboratory size induction furnace at Metallurgical and Materials Engg. Dept., The M. S. University of Baroda. **(Refer figure 2)** The variables for smelting reduction of composite briquettes are shown in **Table 2**. Composite briquettes were charged in molten steel bath in induction furnace with different proportion. Chemical analysis of initial and final product samples was done by OES instrument. Iron yield is achieved 90 to 95 pct in present research work.

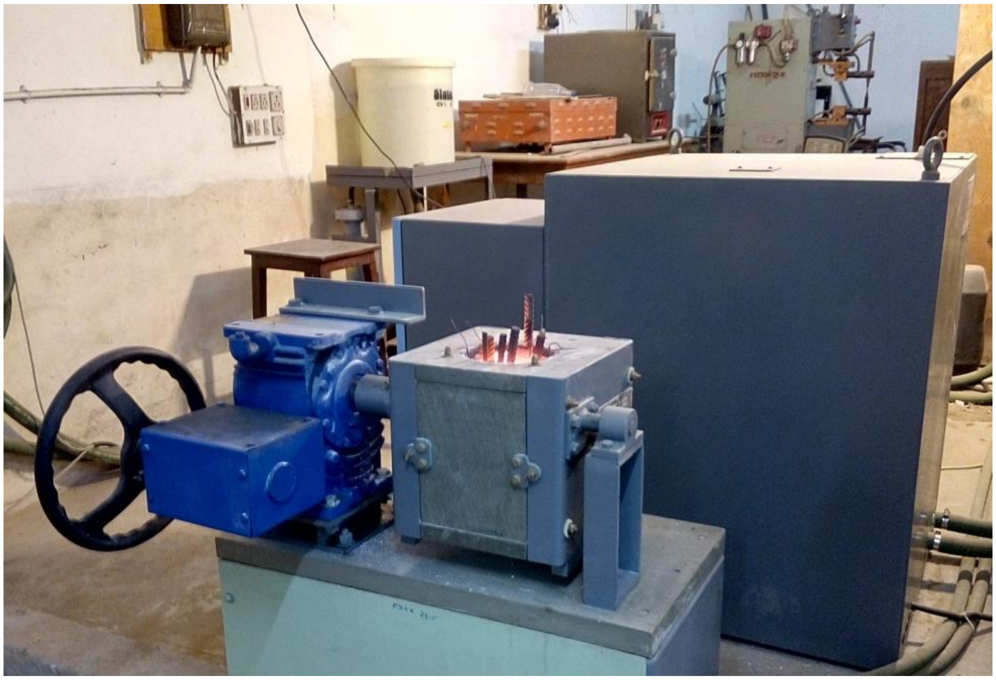

Figure 2: Induction furnace

Table 2: Variable for smelting reduction of composite briquettes

Sr. No.	Variable	Number
1	Composite briquette	4
2	Steel scrap	1
3	pct of briquette charged	4

VI. Testing of produced steel samples

Normalized steel microstructure observed under microscope at different magnification. Hardness of normalized steel was measured by Rockwell testing machine. Due to high carbon content in steel, B scale was used for hardness measurement.

Key findings:

1. Mineralogical studies provide crucial information about texture, morphology, phases present in ore which help to decide suitable beneficiation process
2. BHQ type ore can be upgraded by conventional beneficiation process.
3. Goethite ore can be upgraded effectively by magnetic roasting process.
4. In reduction studies, presence of volatile matters and ash content affect critically on degree of reduction and activation energy.
5. Bulk quantity of composite briquette lowered down molten bath temperature which can be used as coolant and another source of iron and oxygen for steelmaking.

Conclusion:

1. Odisha ore can be processed by conventional beneficiation route but at fine size only. Overall iron recovery value of 59.75 pct is achieved by jigging and tabling operations.
2. Rajasthan ore texture and particle size were not preferred for conventional beneficiation route. Magnetic roasting process achieved recovery of iron in the range of 85 to 90 pct.
3. High compressive strength is achieved by BA with lowest shatter index.
4. Composite briquettes (BA and BB) have shown better reduction behavior.
5. Based on activation energy values of initial and later stage of non isothermal reduction studies, two stage reduction processes is observed in present study.
6. Highest activation energy is obtained in BA composite briquette for isothermal reduction and BB composite briquette for non isothermal reduction.
7. Presence of high ash content in Coke is adversely affects reduction process.
8. Low amount of activation energies indicates reduction is controlled by gasification reactions.
9. SEM images of reduced briquette revealed metalized iron which confirms reduction of iron.

10. In smelting reduction studies, iron yield is achieved 90 to 95 pct which is quite significant at laboratory level.
11. Cold bonded composite briquette are dissolved and reduced in molten bath which is significant for direct use of ore as composite briquette in ironmaking / steel making.
12. Composite briquette can be act as feed material in ironmaking / steelmaking.
13. Slag volume is higher in higher proportion of composite briquette in steelmaking which is due to higher ash and gangue content in briquette.
14. Hardness of normalized cast structure is measured in between of 85 to 95 HRB.

Suggestions for Further Work:

1. Studies of swelling behavior and strength after reduction of the iron ore-coal composite briquettes should be carried out. Such specific investigations are essential for better understanding of the briquette properties and their behavior in reduction/smelting furnaces.
2. Economic estimation of the smelting reduction of composite briquettes by conducting trials at pilot plant level is required for commercialization in future.
3. After complete dissolution of composite briquettes, oxygen lancing can be used to the liquid bath to control carbon and phosphorous in the bath and desulphurization can be carried out in the ladle.
4. By heat balance calculation, it is possible to design the reactor to produce steel directly by continuous charging of composite briquettes.

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