CHAPTER - 1
INTRODUCTION

For the past hundred years, blast furnace (BF) has played a major role in producing hot metal because of their high efficiency, mass production and high degree of gas utilization. BF ironmaking technology has dominated the world scenario as the most economic and widespread resource of liquid iron used in steelmaking. Continuous efforts have been made over the years to improve the overall process working and as a result the modern blast furnace today is considered an extremely efficient metallurgical reactor [1]. Presently, blast furnace contributes over 90 percent (pct) of the world's iron production and the rest coming from direct reduced iron (DRI) plants, mini blast furnaces (MBF), Corex, Ausmelt etc.

The dominance of BF technology, however, has been subject to close scrutiny owing to some inherent limitations in the process such as dependence on coking coal, strict quality norms regarding raw materials, sinter plant and coke oven plant, limited process flexibility and high investment cost for furnace and auxiliary equipment, sophisticated process control systems and facilities to arrest pollution and consequently huge investment. Continued supply of metallurgical coke of consistent quality at a competitive price is becoming difficult now a day. Besides, coke oven batteries are among the most environmentally hazardous reactors so far. The high alumina to silica ratio in Indian iron ore results in higher coke rate and makes furnace operation difficult at lower basicity. This leads to lower productivity and inferior hot metal quality (high silicon content). Scarce availability and high cost of coke / coking coal, high capital cost, large scale of economy and ecological considerations against the conventional BF technology are forcing the iron makers to look for alternative routes of ironmaking [2].

Alternative routes of ironmaking include direct reduction processes producing iron in solid form or smelting reduction processes which produce liquid hot metal directly. A number of direct reduction (DR) processes, both coal and gas based, have been developed and adopted at commercial scale in different parts of the world. DRI has emerged as an excellent feed stock, substituting scrap, for electric steelmaking [3]. Some of the smelting reduction (SR) processes, especially Corex, have also been established at commercial scale.

The industrial development programme of any country, by and large, is based on its natural resources. India is fortunate to have vast reserves of high grade iron ores. The reserves of hematite and magnetite ores are 12.91 and 10.68 billion tonnes (Bt) respectively (Table 1.1) according to an estimate by the Indian Bureau of Mines, Nagpur as on 1st April, 2000 [4]. Of the total hematite ore reserves; about 42 pct [5403 million tonnes (Mt)] are lumps, 34 pct (4326 Mt) fines, 10 pct (1279 Mt) lumps and fines together, 11 pct (1480 Mt) prospective resources, and remaining 3 pct (418 Mt) are blue dust. Indian iron ore deposits, being soft and friable in nature, contain quite a good amount of superfines (-200 mesh) rich in iron content (65 pct and above) and low gangue content. These are known as blue dust. An estimated reserve of blue dust in India is around 418 Mt, which is about 3 pct of the total hematite ore reserves. Around 60 pct of iron ore production comes in the form of fines (including concentrates) during the course of mining operations itself. Further, 10-12 pct lumps become fines while handling, loading/ unloading and while converting them into calibrated lump ore for sponge/pig iron plants/exports. Thus, about 70-75 pct of the total production of the country's iron ore is fines. In addition, there is already a stock-pile of about 40-45 Mt of fines in Indian Iron and Steel Company (IISCO) and Steel Authority of India Limited (SAIL) mines which is creating environmental hazards.

Around 4 Mt of fine slimes (containing 55 to 60 pct iron) are generated every year by ore washing plants in India [5]. Mill scales are also the industrial byproduct, which are produced due to hot working processes. Mill scales are produced in large amount by various processes like hot rolling, hot forging, and heat treatment during quenching. At present, most of the slimes and mill scales are thrown away as waste for land filling and create pollution to the environment, which are not desirable.

Table 1.1: Iron ore reserves in India (as on April 01, 2000) in Mt

Grade	Hematite						Magne-tite (pct)	Total Resou-rces (pct)
	A. Lumps (pct)	B. Fines (pct)	C. Lumps & Fines (pct)	D. Prospective Resources (pct)	E. Others (pct)	Total Hematite [A+B+C+ D+E] (pct)		
High	915.276 (7.09)	139.221 (1.08)	409.095 (3.17)	------	------			
Medium	2822.917 (21.87)	2506.868 (19.42)	421.225 (3.26)	------	------			
Low	1131.915 (8.77)	1325.515 (10.27)	331.754 (2.57)	------	------			
Unspe-cified	533.225 (4.13)	354.187 (2.74)	116.650 (0.90)	------	------			
Sub-total	5403.333 (41.87)	4325.791 (33.52)	1278.724 (9.90)	1480.005 (11.47)	417.940 (3.24)	12905.793 (100)	10682.21	23588.0
						(54.71)	(45.29)	(100)

Note: Figures in parenthesis represent percent.

India has reasonable coal reserves, more than 240 Bt. Out of this, mineable are only 93 Bt. The coking coal, useful for blast furnace iron making, is around 17 Bt (only 18.3 pct), whereas the non-coking coal is 76.0 Bt (81.7 pct) as shown in Table 1.2. Enormous amount of coal fines and coke breezes are produced during coal mining and coking of coal respectively. These fine concentrates can not be processed in DRI reactors such as Midrex, HyL, Rotary hearth and Rotary kiln.

Table 1.2: Coal reserves in India (as on January 01, 2005) in Bt [6]

Type of Coal	Total Reserves	Proved Reserves	Indicated Reserves	Inferred Reserves
Coking coal	32	17	13	02
Non-coking coal	216	76	104	36
Total	248	93	117	38

Utilization of these fines for extracting metal is of vital concern for resource conservation and pollution control. Industrially fine iron ore concentrate is pelletized into spherical balls of 8-20 mm diameter and then indurated up to 1573 K in an induration furnace to enhance the mechanical strength of pellets. In the induration process, fuel (liquid or gaseous) is consumed to supply the heat, thus CO_2 and other pollutants are emitted. Moreover, the capital cost of the induration furnace is also very high. In order to utilize these fines efficiently and economically, a novel concept of cold bonding technique is developed [7]. In the cold bonding concept, the fines of iron bearing oxides and carbonaceous materials are mixed with a suitable binder and optimum quantity of moisture. The mixture is then pelletized into balls of appropriate size. In cold bonding process, the pellets are hardened due to the physico-chemical changes of the binder in ambient conditions or at slightly elevated temperature (400 to 500 K). The challenge in cold bonding process is to find a good binder that ensures the proper physical and mechanical properties of the pellet.

The term composite pellet [8] is being employed here to mean pellet containing mixture of fines of iron bearing oxide and carbonaceous material (coal/coke/char) which has been imparted sufficient green strength for subsequent handling by cold bonding technique. The prepared cold bonded pellet should have sufficient mechanical strength to withstand high temperature and stresses in reduction furnaces.

Interest in ore-coal composite pellet technology had been there for many years without any significant application in iron making. The principal technological problem was to produce pellets with sufficient strength at low cost. Advances in cold bonding technology have brightened the prospects. Cold bonded iron ore-coal/coke composite pellets are very promising feed materials in smelting reduction processes. Interest in composite pellets has grown from the decade of 1980s because of the following advantages [9]:

i) utilization of cheaper resource such as iron bearing fines, coal fines, coke breeze etc and pollution control,
ii) very fast reduction due to intimate contact between reductant and oxide particles,
iii) reduction in energy consumption because cold bonded composite pellets do not require induration,
iv) promising prospect for iron making at small scale with higher production rate,
v) because of their uniform size and convenient form, pellets can be continuously charged into the furnace leading to higher productivity, and

vi) consistent product quality as the chemical composition of composite pellets (input material) does not change.

The concept of smelting reduction process of iron ore, an alternative to BF technology was initiated around 1970. This concept got evolved due to the progressive measures taken in the development of processes for direct reduction of iron ore. The SR process involving both reduction and smelting, are very similar to blast furnace, in which all the reactions take pace in a single reactor. Most of the smelting reduction processes involve the removal of oxygen from iron ore in the solid state followed by further removal of remaining oxygen in liquid phase reduction reactions [10]. Ideally, a smelting reduction process should have near 100 pct reduction of iron oxides in the liquid state in a single stage in a single reactor.

There is shortage of coking coal all over the world in general and in India in particular. On the other hand, India has vast reserves of non-coking coal (i.e., approximately 81.7 pct of total coal reserves), which is widely available and cheapest reducing agent for iron oxide. Hence, non-coking coal based iron making technology has special relevance for country like India. In fact, the need to make non-coking coal based iron making units economically viable has resulted in the development of SR processes, which do not face sticking problems at high temperature. The SR process exploits faster reduction kinetics at high temperature due to enlarged specific contact area between reactants in a dispersed phase and increased mass transport rates due to convection and thereby improves productivity [10]. The process make use of non-coking coal in a broad range of composition and accept a wide range of materials including iron ore fines, plant wastes or inferior grade ore directly. Their process control is relatively simple and they work out economically at small-scale operation catering to varying demands of the market. The process is environmentally acceptable keeping the demands of coming years in view. Some of the upcoming SR processes are Corex, Romelt, HIsmelt, Ausmelt, DIOS, AISI-DOE, Redsmelt, Fastmet, Finex, Iron Dynamics, ITmk3, Kawasaki Star Process etc. Amongst these SR processes, Corex has already been established at commercial scale and Romelt is in advanced stage of commercialization.

The depleting reserves of coking coal, the world over and especially in India, are posing a threat to the conventional blast furnace route of ironmaking. The world's iron makers have sought a replacement process for the blast furnace to allow the elimination of coke ovens and sinter plants, which are under pressure from environmental legislation. Smelting reduction processes of liquid ironmaking are drawing considerable attention because these processes are currently being developed as an alternative to BF ironmaking with the following objectives [11]:

i) to utilize low grade solid fuels and ore fines (the blast furnace requires coke and agglomerated iron ores),
ii) to produce hot metal at lower capital investment and production costs,
iii) to reduce emissions and pollutants during conversion of coal to coke,
iv) to achieve flexibility regarding input of raw materials and selection of operating parameters, and
v) to install small hot metal production units to meet fluctuating market demand and increase production in small steps of capital investment.

Iron ore-coal composite pellets can be used as feed material for smelting reduction. Rate of production is expected to be much higher with composite pellets due to high degree of pre-reduction to the smelting reactor. There have been a few investigations reported in the literature on smelting reduction of iron oxides in contact with Fe-C melts (mostly in slag phase) under various operating conditions. However, fundamental studies on smelting reduction of iron ore-coal composite pellets in liquid metal bath are not available in published literature. Looking into the above aspect, **the objectives of present investigation are two fold:**

i) To prepare composite pellets using various binders by cold bonding techniques in the laboratory and evaluate their properties; this would be a contribution towards development of suitable binder for cold bonding technology.
ii) Fundamental investigation on reduction smelting of iron ore-coal composite pellets in liquid metal bath, including auxiliary studies as back-up investigations with emphasis on kinetics.

Plan of Work:

i) Characterization of raw materials,

ii) Selection of suitable binders for cold bonding of composite pellets,

iii) Preparation of cold bonded iron ore-coal composite briquettes/pellets,

iv) Testing of composite briquettes / pellets,

v) Mass balance calculations,

vi) Fundamental studies on reduction smelting of iron ore-coal composite pellets in liquid metal bath in inert atmosphere,

vii) Bulk dissolution of composite pellets in liquid metal bath and iron recovery (in terms of yield),

viii) Auxiliary studies:

a) Thermal analysis of iron ore-coal composite pellets by TG/DTA,

b) Devolatilization of coal (non-isothermal) by TG/DTA,

c) Scanning electron microscopy of pellets,

d) X-ray diffraction studies of reduced pellets, and

ix) Interpretation of results.