



INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X

Impact factor: 4.295

(Volume 3, Issue 6)

Available online at www.ijariit.com

Chemical, Mineralogical and Metallurgical Characterization of Goethite Rich Iron Ore Sinter

Dr. Kalpataru Rout

Sr. Manager,

Quality Control Laboratory, NINL, Duburi, Jajpur, Odisha 755026, India.

Krout1161@gmail.com

Abstract: *In this paper the influence of structural water present in goethite rich ore fines on sinter properties like mean size, RI, RDI, TI, AI and microstructure were studied. For this three plant sinters with different basicities (A1, A2 and A3) were experimentally produced varying the raw mix. From the study on variable basicity, it is found that increased basicity has good effects on the sinter properties. The desired norms of metallurgical properties for good quality sinter required for large size blast furnace met with increased tumbler index and decreased abrasion index. The RI is also better in highly fluxed sinter A3 and the RDI is low. All these are happening due to availability of more free lime and porosity. The mean-size of sinter also increases with increase of basicity. The reducibility index and RDI of sinter A2 and A3 appear to be similar although there is a variation in chemistry and basicity, this may be attributed to use of more micro-fines in raw material of sinter A3. The specific consumption of coke rate is highest for sinter A3 is also due to more micro-fines in raw materials. From the microstructure it is found that in sinter A1 more magnetite and less ferrites are developed in comparison to A2 and A3. The silicoferrites of calcium and aluminium (SFCA) developed in sinter A2 and A3 are acicular in structure which provides better strength to the sinter. Also the porosity is more in case of A2 and A3 which can accelerate the reducibility process.*

Keywords: *Abrasion Index, Ferrites, Goethite Ich Iron ore, Reducibility Index, Reduction Degradation Index SFCA, Sinter, Tumbler Index, etc.*

INTRODUCTION

During mining of iron ores, lots of fines (<10 mm) are generated which are not suitable for direct use in the blast furnace for iron making. Agglomeration technique applied for the coarser fines is generally done in a process known as “sintering” by application of heat where partial fusion of the constituent material occurs. The sinter process was invented more than a century ago. In its early days it was considered as an evil. However, during and after 1960s, sinter has been recognized as an outstanding blast furnace burden world over. Earlier only acid sinters were produced and the use of sinters in the BF burden was limited to 30 % only. Subsequently fluxed and super-fluxed sinters were produced and recognizing the advantages of sinter, the use of sinter was increased to more than 70%. These days many blast furnaces are using even more quantity of sinter.

Background

Indian iron ores have been extensively studied with respect to their geology, mineralogy, geochemistry and genesis (Sarkar *et al.*, 1969; Banerji, 1977; Chakraborty *et al.*, 1980; Rai *et al.*, 1980; Acharya *et al.*, 1982; Radhakrishna *et al.*, 1986; Chakraborty and Majumder, 1986; Devaraju and Laajoki, 1986; Mahabaleswar, 1986; Chadwick *et al.*, 1986; Beukes, *et al.*, 2003; Mohapatra *et al.*, 2008). The beneficiation studies are focused mainly towards reducing the alumina content of the ores (De *et al.*, 1995; Rao *et al.*, 2001; Upadhyay and Venkatesh, 2006). However, all the hematitic ore deposits of India, although broadly similar in nature, have their specific problems which may be generic or very specific to that deposit. It is not only the Fe content, but the mineralogy, the type of associated gangue minerals, the physical and metallurgical properties would decide the type of utilization of the ores. If the ores are high-grade (Fe > 64 %) and are able to produce lumps (>10mm), then these can be directly fed into the blast furnace. If the grades are still higher and calibrated lumps of 18-20mm can be generated, then the ores can be used to produce spong-irons (DRI). However, the ore bodies are unable to produce lumps then the fines (-10mm to 0.15mm) are to be beneficiated and agglomerated (sintered) in order to make them suitable for extraction of metal.

The ultra-fines (below 0.15 mm) after suitable beneficiation, can be formed into balls called pellets (~10mm) which can be used in the reduction furnaces after attaining proper physical properties. If the ores are very low-grade ores such as limonite, red ochre or yellow ochre, then these are used as colour pigments. Some have application in powder metallurgy. Besides the above, some ores although contain less gangue material, can produce lumps but still cannot be directly used in the blast furnaces. **Goethite is one such ore that contains water in its chemical structure which makes 100 % utilization of this ore lumps unsuitable for direct utilization in the blast furnaces.** Unlike in Australia (Clout, 2006), in India such ores have not drawn enough attention of the researchers and therefore, have been least studied with respect to their associated problems in iron making and any other possibility of utilization. The chemical analysis results goethitic rich iron ores from Daitari, Odisha showed that Fe is the major constituent (63.12 %) with Al₂O₃ (1.55%), SiO₂ (1.87%), S (0.012%), P (0.092%), Mn (0.217%), Na₂O (0.09%), K₂O (0.052%), TiO₂ (0.09%) being the minor constituents and loss on ignition 5.8%. Powder X-ray diffraction coupled with thermal and optical micrograph analyses showed the presence of significant amount of goethite in raw sample, which progressively converted into hematite due to loss of structural water upon heating and nearly complete conversion was observed at approximately 400 °C (Behera *et al.* 2010). SEM-EDX found that hematite contains 69.94 wt% Fe, which is almost close to its theoretical composition, goethite contains approximately 62–63 wt% Fe. The contaminants in goethite, Al and Si, might be due to clayey impurities in micron level. With goethite being in a supergene phase, formed due to weathering and alterations, entrapment of other elements is not abnormal. (Behera *et al.* 2012).

Objectives of Sintering: Although the primary aim of sintering is to agglomerate the iron ore fines, many more objectives are fulfilled due the sintering process. These are:

1. To increase the size of ore fines to a level acceptable to the blast furnace
2. To form a strong agglomerate with high bulk reducibility
3. To remove the volatiles like combined water in iron ore, CO₂ from carbonates, sulfur and arsenic present in the base mix
4. To incorporate flux in the burden mix
5. To utilize some of the waste generated within steel plants
6. To give a consistent quality feed to the blast furnace

Out of the above six the first and last one is the must. The second objective is dependent on the nature of the ore and other economic considerations of carrying out the process of sintering. The removal of volatiles is only incidental that also depends on the nature of the ore. The main attention is therefore, focused on to the extent to which flux can be incorporated in the sinter mix without compromising other properties of the produced sinter. The main natural fluxes used for iron making in blast furnace are limestone and dolomite. These fluxes are charged either in the blast furnace in lump form or through sinter. In the later case the fluxes calcined during sintering and enter the blast furnace in a combined form along with the oxide burden. This reduces the thermal load in the blast furnace as a result of prior calcinations outside the furnace and thus reduces the coke rate (Singh and Deo, 1995). Incorporation of flux in the burden through sinter, therefore, greatly improves the blast furnace performance, since the formation of slag then becomes relatively easy and it forms at the correct level in the blast furnace.

Parameters Affecting Sinter Quality

Generally before sintering a charge-mix is prepared that consists of iron ore fines, fluxes (limestone and/or dolomite), fuel (coke breeze), sinter return-fines, and sometimes some waste-recycling plant materials. Therefore, efficiency of producing good quality sinter depends on many characteristics of the charge mix. These qualities of the charge mix should be adjusted to the optimum to obtain best possible quality of sinter without affecting the production rate adversely. The major parameters which affect the quality of sinter are:

Particle Size

Iron ore fines: The larger sized iron ore fines (> 10mm) does not take part in agglomeration rather is sometimes came un-sintered. The larger sized iron ore will segregate at a particular portion where sintering will be fast leaving behind the other portion. This situation will generate heterogeneous sinter chemistry. The smaller sized iron ore fines (<100 mesh) shall reduce the permeability of sinter bed and this in turn will generate more sinter return-fines and thus productivity of sinter machine is affected. So the ideal size distribution of iron ore fines must be 10 to 0.15 mm and mean size of the ore fines shall be 3 to 5 mm.

Coke Breeze: In integrated steel plants, coke breeze is a by-product of coke oven battery which is used as fuel for sintering process. The coke crushing index should be 90% (-3.15mm) and the -0.25 mm percentage should be within 25%. The larger sized coke particle produces a large reduction zone which increases the FeO content in sinter. The more undersigned coke breeze not only reduces the permeability of bed but also flares immediately without sintering the material; this generates more sinter return-fines.

Fluxes: Lime stone, dolomite, dunite, pyroxinite are the main source of fluxes used in Indian iron and steel industry. However, calcined lime has an additional advantage in the sinter process like improvement in mean size, tumbler index and reducibility index. The higher size flux generates free calcined lime faces in the sinter. As it is known that calcined lime is very much hygroscopic, the sinter gets decrepitated. The crushing index of fluxes should be 90% minimum.

Fuel Content: The Proportion of fuel in the charge has a bearing on the constitution of the sinter. Fuel content is usually in the range of 6.8%.

Moisture Content: The presence of moisture in the sinter mix maintains proper permeability in the bed during sintering. The rate of rise of temperature levels is more rapid in wet than in dry.

Moisture also increases the specific volume of air required for sintering.

Alumina Content: The extent of alumina content should be maintained to the optimum level to control the quality of sinter (De et al, 1992). Alumina content in the range of 1-2% is desired. Excess alumina makes the slag more refractory and this problem is overcome by increasing the basicity (CaO/SiO₂). It leads to increase in slag volume, consumption of more coke and decrease in productivity.

FeO Content: The main source of FeO in sinter is iron ore fines, mill scales. The FeO content of the raw materials have a significant impact on the burn through point and tumbler index. Burn through temperature and tumbler index would increase with increasing amount of FeO content in the sinter raw material. In Indian steel plants it is kept at 8 – 11%.

Process Controls: In addition to the material controls, there are many process parameters which can be controlled and also if necessary, modified. These parameters can also affect the sinter properties. Some important controls are:

Burn through Point is a point where the whole sinter process gets completed. During the process of sintering after the ignition of top layer, suction of air through the permeable bed gets started. The amount of suction of air gets increased with the increasing number of wind boxes. Depending upon the FeO content the complete suction of air could be achieved in the appropriate wind box. Burn through temperature is a high temperature relatively compared with the temperature present in other wind boxes. It is aimed at the range 340 - 380°C either by changing the machine speed or by increasing the suction. Both machine speed and suction pressure is controlled manually.

The Sinter Bed Permeability is greatly affected by amount of moisture in the mixed material and amount of fines present in the raw materials. Permeability of sinter bed affects the suction of air through the sinter bed. The process of suction is good when the permeability of sinter bed is optimum. Very low and high permeability of bed is also not desirable.

In addition there are many more process controls such as: sinter strand regulation (machine speed), sinter bed depth, air-flow etc.

Sinter Properties: Apart from the desired chemical property which can be controlled at the beginning, the strength and reducibility are the most important physical and physico-chemical properties that determine the suitability of the sinter to be used. Therefore, it is imperative to evaluate the produced sinters by the tests like tumbler index (TI), Abrasion index (AI), reducibility index (RI), reduction degradation index (RDI) and softening –melting test. However, for routine operations generally TI, SI, RI and RDI are determined.

Tumbler Index: The Tumbler Index is generally determined following IS: 6495-1984. Tumbler test measures the susceptibility of the material to breakage due to abrasion during handling, transportation, charging on to the blast furnace BLT system as well as inside the furnace itself. In general higher is the tumbler index the better the sinter will stand during handling. The target for tumbler index is +70%.

Reducibility Index: The reducibility test is carried out following IS: 8176/76 where 500gm of sinter sample (size: 10-15mm) is taken in a reaction vessel and reacting gas (CO: 30%; N₂:70%) is passed (15 lit/min) for 180 minute at about 950°C. The result is expressed as:

$$\% \text{ Degree of reduction} = (n_1 - n_2 / n_1) \times 100$$

Where n_1 = no. of moles of O₂ initially combined with iron

n_2 = no. of moles of O₂ combined with iron after experimental time, t.

Reduction Degradation Index: Reduction degradation of sinter takes place in the upper part of the blast furnace at 500-600°C causing disintegration of sinter and generation of fines which affect the gas permeability inside the blast furnace. For this test, about 500 gm of sample (size: 10-15mm) is taken in a reaction vessel where reacting gas is passed at 15 lit/min for one hour at a temperature of 550°C. After the sample is cooled another tumbling test is done and the result is presented.

Characteristics of a Good Sinter: Normally there is an inverse relationship between RI and RDI of sinter. Many properties do not go hand in hand and therefore, a balance has to be maintained between various properties. A sinter is generally considered 'good' if the properties are: TI: 70 minimum (%+6.3mm); Abrasion Index: 5.0 max (% -0.5 mm); FeO: 8-10%; Moderate basicity: 1.5-2.0; reducibility index: above 65% and RDI: less than 30%. The parameters like RI and RDI are considered to be the most important quality indicators for the selection of sinter as a burden material. However, the effects of the chemical constituent present in the sinter influence these quality parameters to a great extent. An increase in RI and lowering in RDI value makes a sinter suitable for its use in blast furnace. High productivity blast furnace demands a low RDI for sinters where as higher RI is important for achieving low fuel rate. High reducibility index (>65%) of sinter is achieved by reducing FeO and SiO₂ content in sinter, reducing coke consumption, increasing bed height and controlling coke size. A value of 70 (% +6.3mm) for ISO tumbler index is usually acceptable even though the best sinters have ISO strength indices between 70 and 80.

Experimental

Brief description of the process: The required raw material for sintering is stored in different proportionate bins. The material is then conveyed in required proportion to MND (Mixing and Nodulising Drum) with a common conveyor. The raw material is uniformly mixed and required amount of water is added in MND. The raw mix is then stored in raw mix hopper in sinter plant main building. Sinter machine is a series of pallets rotating between charging hopper and sinter breaker.

The Product Sinter: The product sinter is analyzed for its chemical composition using a Phillips-axios XRF and cross-checked by wet chemical methods. Tumbler index, reducibility index, reduction degradation indices are measured using Eastman Crusher make tumbler index apparatus, Naskar-make RI-RDI instrument respectively. The results of various analyses are given in tables 6.7 to 6.9.

Plant Sinters with Variable Basicity: Since there is less flexibility in the plant process parameters to change because of the adverse effects on the productivity, only three plant-scale experiments were carried out changing the raw material inputs especially to change the basicity in order to visualize the effects of basicity on the sinter properties of the Daitari goethitic iron ore. These experiments/sinters are termed as A1, A2 and A3 that were produced with basicities of 1.34, 1.58 and 1.80 respectively. The raw-material characteristics, and sinter chemical physical properties are given Tables (1.10 – 1.14). The microstructure is given in the figures (Fig. 1.1) and phase volume relation obtained as for ASTM E562 and E1245.

Table 1.10: Chemical Composition and Granulometry of Iron Ore Fines

ID	T.Fe	SiO ₂	Al ₂ O ₃	LOI	MC	+10 mm	+1 mm	+ 0.5 mm	- 0.5 mm	Al ₂ O ₃ /SiO ₂
A1	61.28	1.99	1.86	7.61	9.05	6.16	59.53	9.64	24.67	1.16
A2	61.78	1.86	1.48	6.00	7.38	6.49	62.99	7.70	22.82	0.76
A3	61.15	1.97	2.25	6.12	5.88	2.43	32.97	20.36	44.24	0.99

Table 1.11: Chemical Composition and Granulometry of Fluxes

ID	T.Fe	SiO ₂	Al ₂ O ₃	CaO	MgO	+3mm	-3mm
Limestone for A1	0.78	7.72	1.06	43.12	5.95	13.14	86.86
Limestone for A2	0.48	4.85	0.47	49.48	3.56	16.52	83.48
Limestone for A3	0.69	7.83	0.93	44.89	4.19	18.29	87.71
Dolomite for A1	4.65	6.18	1.15	29.24	14.39	6.91	93.09
Dolomite for A2	4.41	5.58	1.01	26.97	17.81	5.48	94.52
Dolomite for A3	0.74	4.99	0.84	27.15	20.2	7.26	92.74

Table 1.12: Proximate Analysis and Granulometry of Coke Breeze

ID	MC	VM	Ash	FC	+3mm	-3mm
Coke breeze for A1	5.26	2.38	17.56	80.06	19.46	80.54
Coke breeze for A2	3.72	2.32	17.88	79.80	5.92	94.08
Coke breeze for A3	2.22	2.50	17.50	80.00	21.2	78.8

Table 1.13: Chemical Composition of the Product Sinter

ID	T.Fe	FeO	SiO ₂	Al ₂ O ₃	CaO	MgO	Al ₂ O ₃ /SiO ₂	Basicity	Ex- Base
Sinter A1	57.32	9.36	5.42	2.37	7.25	1.99	0.55	1.34	1.83
Sinter A2	56.85	9.82	5.36	2.11	8.48	2.24	0.39	1.58	3.12
Sinter A3	54.53	8.45	5.80	2.68	10.45	1.79	0.57	1.80	4.65

Table 1.14: Granulometry of the Product Sinter

ID	+40 mm	+25 mm	+10 mm	+5 mm	-5 mm	MS
Sinter A1	1.1	6.1	41.7	43.3	7.8	13.22
Sinter A2	2.5	8.4	46	36.9	6.2	14.83
Sinter A3	5.4	10.6	34.4	44	5.6	15.34

Table 1.15: Physical Properties and Coke rate of the Product Sinter

ID	TI	AI	RI	RDI	Sinter Return %	Specific Consumption of Coke Breeze
Sinter A1	64.2	7.2	63.5	35.3	31.40	68.84
Sinter A2	67.9	6.8	66.8	32.9	36.00	79.00
Sinter A3	69.8	6.4	66.9	32.6	45.96	92.00

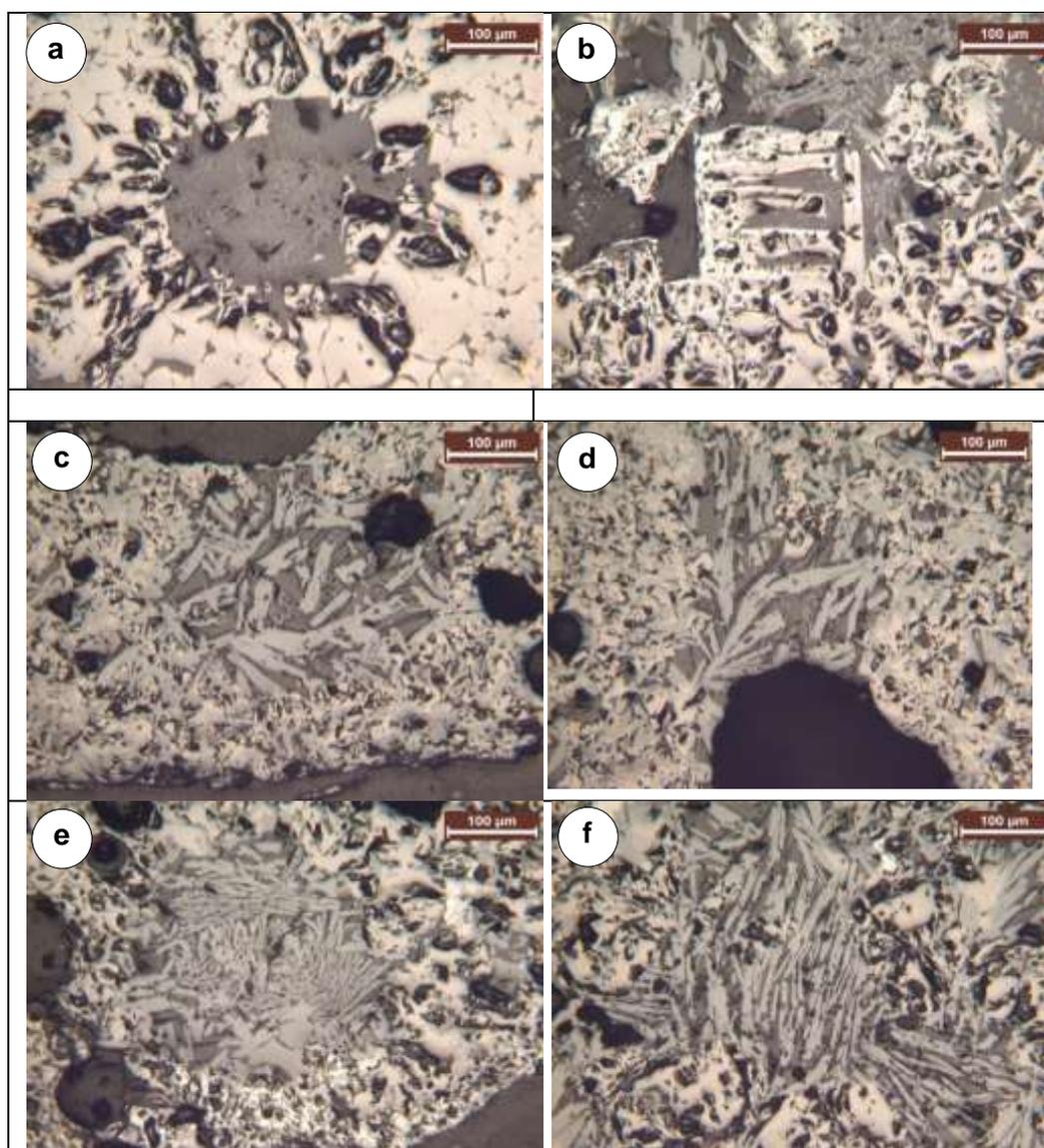
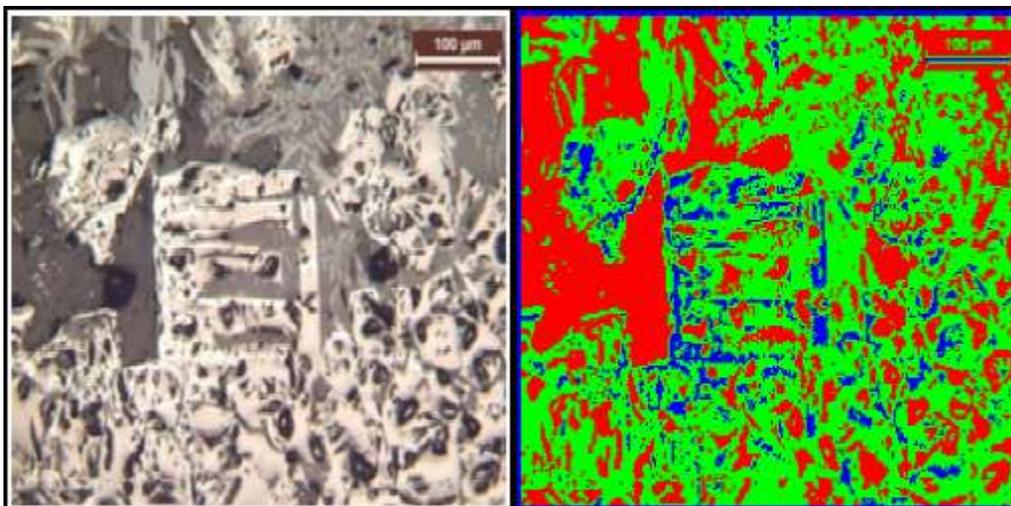


Fig. 1.1: Microstructure of Sinters with Variable Basicity. a and b are of sinter A1; c and d are of Sinter A2; e and f are of Sinter A3.

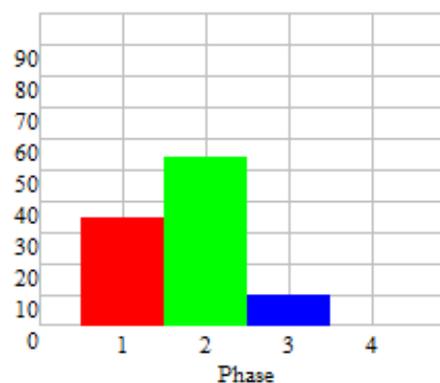
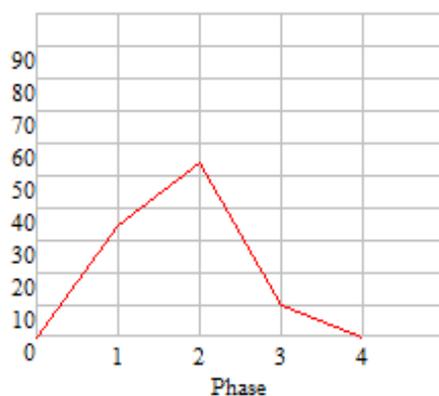
It can be observed from figure 6.1 that in sinter A1 more magnetite and less ferrites are developed in comparison to A2 and A3. The silicoferrites of calcium and aluminium (SFCA) developed in sinter A2 and A3 are acicular in structure which provides better strength to the sinter. Also the porosity is more in case of A2 and A3 which can accelerate the reducibility process.

PHASE AND VOLUME ANALYSIS ASTM E562 &E1245

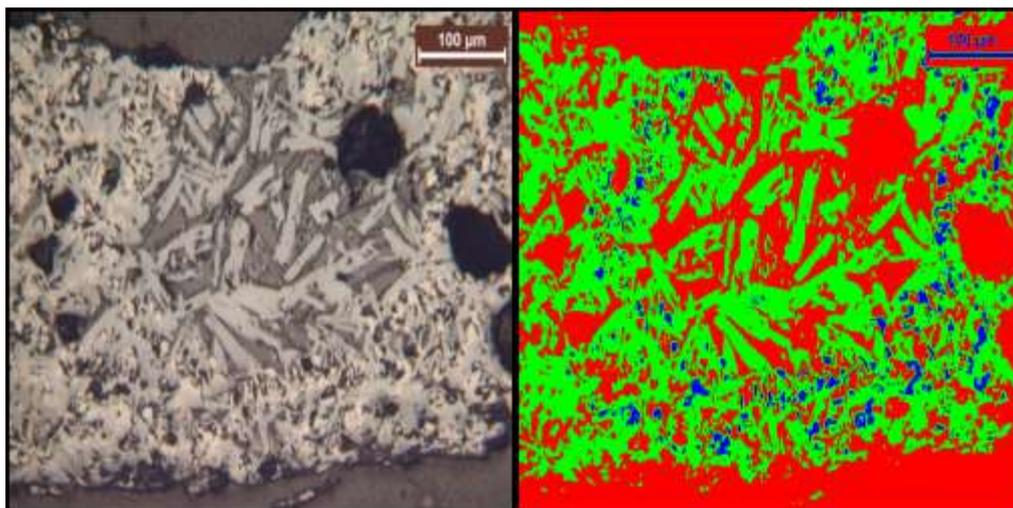
MICROSTRUCTURE TEST REPORT WITH BASICITY 1.34 (Fig: 1.2)



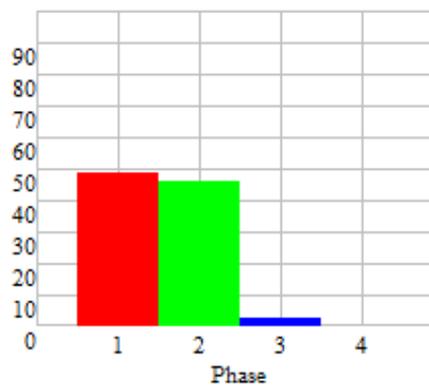
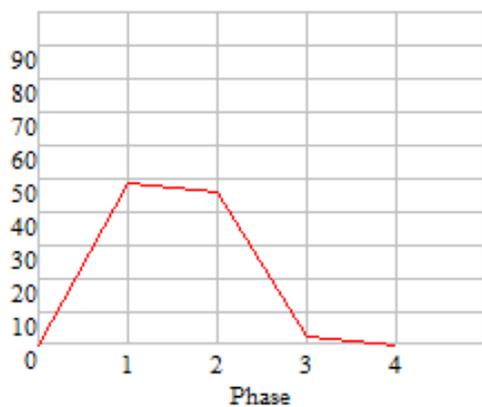
SNo	NAME	AREA	AREA_PER
1	pores	118324.100 Micron Sqr	35.035
2	magnetite	183095.568 Micron Sqr	54.214
3	Fyalite	36308.864 Micron Sqr	10.751



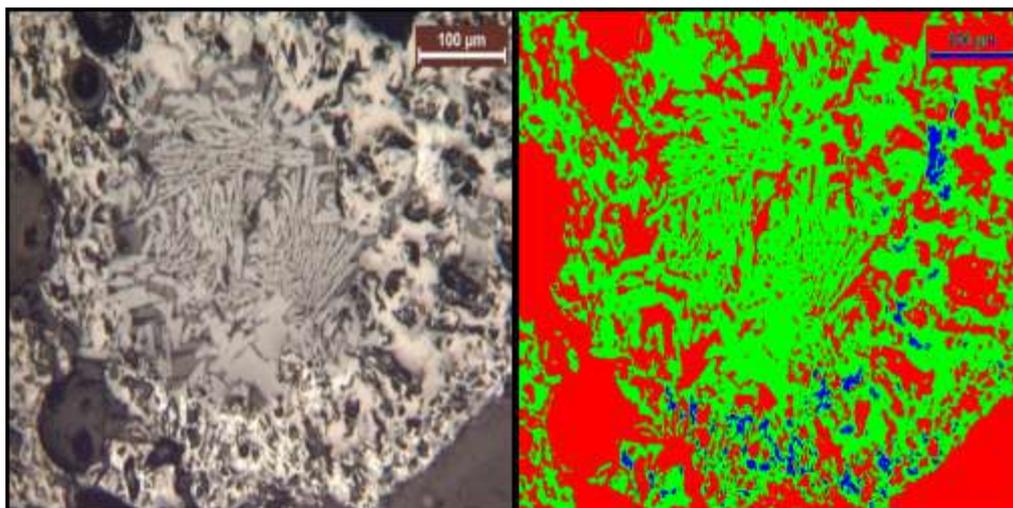
MICROSTRUCTURE TEST REPORT WITH BASICITY 1.58 (Fig: 1.3)



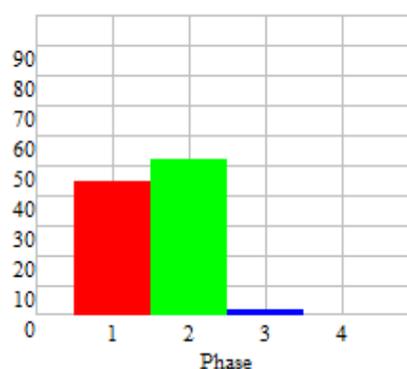
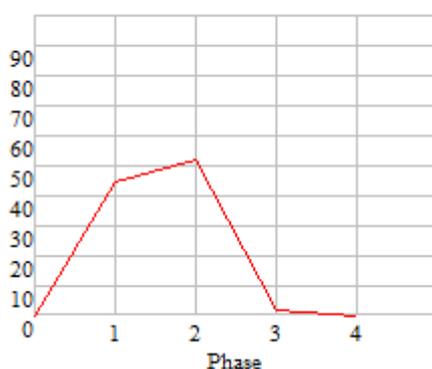
SNo	NAME	AREA	AREA_PER
1	Pores	875817.175 Micron Sqr	49.444
2	SFCA	832403.047 Micron Sqr	46.993
3	Fyalite	63109.418 Micron Sqr	3.563



MICROSTRUCTURE TEST REPORT WITH BASICITY 1.80 (Fig: 1.4)



SNo	NAME	AREA	AREA_PER
1	Pore	748753.463 Micron Sqr	45.213
2	SFCA	871121.884 Micron Sqr	52.602
3	Fyalite	36177.285 Micron Sqr	2.185



RESULTS & DISCUSSIONS

From the above study on variable basicity, it is observed that increased basicity has good effects on the sinter properties. The TI is significantly improved and abrasion index decreases which is good. The RI is also better in highly fluxed sinter A3 and the RDI is low. All these are happening due to availability of more base. The mean-size of sinter also increases with increase of basicity. The reducibility index and RDI of sinter A2 and A3 appear to be similar although there is a variation in chemistry and basicity, this may be attributed to use of more micro-fines in raw material of sinter A3. The specific consumption of coke rate is highest for sinter A3 is also due to more micro-fines in raw materials. The quantification of phases microstructures indicates that sinter with basicity 1.34 area is covered with porosity 35.035%, magnetite 54.214% and fyalite 10.751 %. Sinter with basicity 1.58 area is covered with porosity 49.444%, SFCA 40.993 and fyalite 3.563%. Sinter with basicity 1.80 area is covered with porosity 45.213%, SFCA 52.602% and fyalite 2.185%. There is a uniform distribution of fyalite over the SFCA which causes its optimum properties. All the sinters are found to be spongy which may be due to release of structural water from the goethite.

CONCLUSION

A moderate quality of sinter can be produced from the goethitic iron ore fines. The sinters produced with basicity 1.80 yield an optimum combination of physico-chemico and metallurgical properties due to highest SFCA, 52.602% and lowest fyalite, 2.185% which certainly accepted and required by any blast furnace. The sinter with basicity 1.34 falls in a dangerous zone of sinter due development of large quantity of detrimental phases like ductile magnetite and less reducible fyalite.

REFERENCE

1. Acharya *et al.*, 1982; Acharya, S., Amstutz, S.C. and Sarangi, S.K. (1982): Diagenetic crystallization and migration in the banded iron-formation of Orissa, India. In: G.C. Amstutz and others (Eds.). *Ore Genesis – the State of the Art*. Springer-Verlag, 442-449.
2. Banerji, 1977; Banerji, A.K. (1977): On the Precambrian banded iron formations and the manganese ores of the Singhbhum region, Eastern India. *Economic Geology*, **72**, 90-98.
3. Behera, R.K., **Rout, K.**, Nayak, B. and Das, N.N. (2010) Mineralogical Characterization and sorption properties of goethite rich iron ore from Daitari, Orissa, India: In proceedings of XI International Seminar on Mineral Processing Technology (MPT 2010), R. Singh, A. Das, P.K. Banerjee, K.K. Bhattacharyya and N.N. Goswami Edn, *Allied Publishers Pvt. Ltd.*, New Delhi, Vol. I, p. 16.
4. Behera, R.K., **Rout, K.**, Nayak, B. and Das, N.N. (2012) Removal of Selenium and Arsenic Oxyanions using Natural Goethite-Rich Iron Ore from Daitari, Orissa, India: Effect of Heat Treatment, *Adsorption Science & Technology (Multi-Science, UK)*, **30** (10), 867-879.
5. Beukes, *et al.*, 2003; Beukes, N.J., Gutzmer, J. and Mukhopadhyay, J. (2003): The geology and genesis of high-grade hematite iron ore deposits, *Applied Earth Science (Transactions IMM-B)*, **112**, 18-25.
6. Chadwick *et al.*, 1986; Chadwick, B., Garrioch, N.H.G., Ramakrishnan, M. and Viswanatha, M.N. (1986): Mineral composition, textures and deformation in Late Archaean Banded Iron-Formation rich in magnesianiebeckite and aegirine, Bababudan, Karnataka, Southern India. *Journal of the Geological Society of India*, **28**, 189-200.
7. Chakraborty and Majumder, 1986, Chakraborty, K.L. and Majumder, T. (1986): Geological aspects of the Banded Iron-Formation of Bihar and Orissa, *Journal of the Geological Society of India*, **28**, 109-133.
8. Chakraborty *et al.*, 1980; Chakraborty, K.L., Chakraborty, T.L. and Majumder, T. (1980): Stratigraphy and structure of the Precambrian Banded Iron-Formation and chromite bearing ultramafic rocks of Sukinda valley, Orissa. *Journal of the Geological Society of India*, **21**, 398-404.
9. Clout, 2006 Clout, J.M.F. (2006): Iron formation-hosted iron ores in the Hamersley Province of Western Australia, *Applied Earth Science (Transactions IMM-B)*, **115**, 115-125.
10. De *et al.*, 1995; De, A., Gupta, S.S., Bahadur, S., Chatterjee, A. and Mukherjee, T. (1995): Tata Steel's experience in sintering of high alumina iron ore fines, *Indian Mining and Engineering Journal*, 1995.
11. Devaraju and Laajoki, 1986; Devaraju, T.C. and Laajoki, K. (1986): Mineralogy and mineral chemistry of the manganese-poor and manganiferous iron-formations from the high-grade metamorphic terrain of Southern Karnataka, India. *Journal of the Geological Society of India*, **28**, 134-164.
12. Mahabaleswar, 1986; Mahabaleswar, B. (1986): Mineral chemistry of the silicate mineral phases of Banded Iron-Formation of high-grade region, Karnataka, *J. Geological Soc. India*, **28**, 165-178.
13. Mohapatra *et al.*, 2008; Mohapatra, B.K., Singh, P.P., Mishra, P. and Mohant, K. (2008): Detrital iron-ore deposits in the Iron Ore Group of rocks, northern Orissa, eastern India, *and Aust.J. Earth Sci.*, **55**, 1139-1152.
14. Radhakrishna *et al.*, 1986; Radhakrishna, B.P., Devaraju, T.C. and Mahabaleswar, B. (1986): Banded iron formation of India. *J. Geological Soc. India*, **28**, 71-91.
15. Rai, K.L., Sarkar, S.N., and Paul, P.R. (1980): Primary depositional and diagenetic features in the banded iron formations and associated iron deposit of Noamundi, Singhbhum district, Bihar, India. *Mineralium Deposita*, **15**, 189-200.
16. Rao, M.S., Roy Choudhury, B., Rao, P.V.T. and Bajjal, A.D. (2001): Lowering alumina in Noamundi iron ores. *Tata Search-2001*.
17. Santosh Kumar, Jha R. K. and Banerjee N. G (2011). Behaviour of NINL Blast Furnace with 100% Calibrated Lump Iron Ore. *Journal of Materials & Metallurgical Engineering* Volume 1, Issue 2, June, 2011, Pages 1-8.
18. Sarkar *et al.*, 1969; Sarkar, M., Banerjee, A., Pramanick P.P. and Sarkar, A.R. (2006): Use of laterite for the removal of fluoride from contaminated drinking water, *J. Colloid Interface Sci.*, **302**, 432.
19. Upadhyay and Venkatesh, 2006; Upadhyay, R.K. and Venkatesh, A.S. (2006): Current strategies and future challenges on exploration, beneficiation and value addition of iron ore resources with special emphasis on iron ores from eastern India. *Appl. Earth Sci. (Transactions IMM-B)*, **115**, 187-195.