SINTERING CHARACTERISTICS OF ITAKPE AND AGBAJA IRON ORE CONCENTRATES BLENDS

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A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA. NIGERIA

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NOVEMBER, 2006.

DECLARATION

I, declare that the work in the thesis entitled 'Sintering characteristics of Itakpe and Agbaja Iron ore concentrates blends' has been performed by me in the Department of Metallurgical Engineering under the supervisions of Dr. I.A. Madugu and Dr. S.A. Yaro.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

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Suleiman Idawu Yakubu	***Signature***	***Date***

CERTIFICATION

This thesis entitled 'SINTERING CHARACTERISTICS OF ITAKPE AND AGBAJA IRON ORE CONCENTRATES BLENDS' by Suleiman Idawu Yakubu meets the regulations governing the award of Master of Science Degree of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dr. S.A. YARO ***Date***
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Prof. J.U. Umoh ***Date***
Dean, Postgraduate School

DEDICATION

This project is dedicated to ALMIGHTY ALLAH, my beloved children. Jumai Aisha Orohachi. Danjuma Suleiman Onoru-oiza and Abdulshakuur Ohida, my beloved wife, mallama Jamila Uno-oiza and my parent Mallam Suleiman Iboyi Ochu and Mallama Medinat Suleiman Ochu . May almighty ALLAH rewards us abundantly (Amin).

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ABSTRACT

This research investigated the sintering characteristics of sinter blends produced from Agbaja iron ore concentrate of high phosphorus (P_2O_5 = 1.50 – 2.14%) and low silica content and Itakpe iron ore concentrate of low phosphorus (P = 0.03%) and high silica in order to produce fluxed sinters suitable for pig iron production. The ores (Agbaja and Itakpe) were concentrated using conventional beneficiation techniques and then blended in the ratios of 10-70% Agbaja and 90-30% Itakpe. The blends were mixed with coke breeze, limestone and moisture to produce fluxed sinters. The physical and chemical characteristics of the produced sinters vis-a-visa abrasion resistance, shatter index, tumbler index, reducibility, reduction decrepitating and chemical composition were determined. The results obtained revealed that both the physical and chemical properties of the produced sinters compared favourably with existing blast furnace specifications for sinters. However, the sinter with 10% Agbaja and 90% Itakpe possessed physical and chemical properties that are close to the specified properties of sinter for use in the blast furnace for Pig iron production. Therefore, sinter blend with 10% Agbaja and 90% Itakpe iron concentrates can be recommended for use in blast furnace for the production of pig iron.

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NOTATIONS

P_2O_5	-	Phosphorous pentoxide
P	-	Phosphorous
%	-	Percentage
^0C	-	Degree Celcius
mt	-	Millions tonnes
^0E	-	Degree East
km	-	Kilometres
↔	-	Reversible equation
mm	-	Millimetre
Fe^{++}	-	Iron charge
SiO_2	-	Silicon oxide
CaO	-	Calcium oxide
Al_2O_3	-	Aluminium oxide
TiO_2	-	Titanium oxide
MgO	-	Manganesium oxide
Mn	-	Manganese
S	-	Sulphur
CO_2	-	Carbon dioxide
H_2O	-	Steam
C	-	Carbon
L.O.I.	-	Loss on ignition
ASCL	-	Ajaokuta Steel Company Limited

NMDC	-	National Metallurgical Development Centre
Kg	-	Kilogram
RMRDC	-	Raw Materials Research and Development Council
μm	-	Micron (10^{-3})
AIV	-	Abrasion index value
SIV	-	Shatter index value
TIV	-	Tumbler index value
RIV	-	Reducibility index value
RDIV	-	Reduction Decrepitation index value
cc	-	Chemical compositon
X	-	Agbaja iron ore concentrate
Y	-	Itakpe iron ore concentrate
Ispat	-	Means Steel in India
≤	-	Less than or equal to
LD	-	Linz-Donawitz (oxygen process of steel making)

CHAPTER ONE

1.0 INTRODUCTION

In order to ensure the survival of any industry, raw materials input must be critical and continuously be in supply both in large quantity and in good quality. Even though Nigeria is blessed with large quantity of iron ore deposit of about three billions (3×10^9) metric tonnes, these deposit cannot be used directly in pig iron production without beneficiation because some of them are of low grade and contain impurities, which can be detrimental to the properties of the steels to be produced. Some researches have already been carried out on the beneficiation of some of these ores for use for pig iron production by, Adigwe (1973), and Oloche et al., (1996).

Eventhough Nigeria is blessed with large reserves of proven and unproven iron ore deposits, only one of the deposits in the proven reserves is currently being exploited and processed that is the Itakpe iron ore deposit. This deposit has an estimated reserve of about 200 millions (200×10^6) metric tonnes and has been earmarked to be supplied to Ajaokuta and Delta steel plants. However, this deposit, based on the designed requirement of the Ajaokuta plant, will only last for 25 years (Adigwe, 1983). This is grossly inadequate for the establishment of a formidable foundation for a well- projected and integrated iron and steel plants. Also the Agbaja iron ore deposit, eventhough the largest iron ore deposit in Nigeria estimated at over 2 billions (2×10^9) metric tonnes, has a very high phosphorous content in addition to its extremely fine grained texture. This feature has discouraged its utilization to date (BRGM Report, 1983). With these apparent problems it has become very necessary to find ways of using this vast deposit of iron ore.

The most probable way to utilize the large quantity of iron ore is by blending with other iron ores with lower phosphorous content. Therefore, the objective of this work is to blend Itakpe super concentrate of low phosphorous with the Agbaja concentrate of high phosphorus so as to produce a sinter mix that can serve as feed to blast furnace for pig iron production.

Kurt (1980) said that both sinters and pellets are used as feed with iron but sinters are the common and suitable sources of feeds to the blast furnace. The process of sintering comprises high temperature-treatment (above 1000^0C) of iron fines on a moving grate, blended with fluxes and coke breeze (finely divided coke) to form hard lumps or iron-rich material suitable for use as blast furnace feed (Williams, 1983). In iron ore sintering, the aim is always to produce a strong but porous agglomerate from a sandy uncompacted mass. Tupkary et al., (1998) also noted that in order to obtain smooth and hard "rapid driving operation", the burden charged in the furnace should ideally posses the following physical and chemical properties.

Physical properties

1. A close size range with minimum of fines.
2. An ability to withstand the physical stresses incurred on being transported to the furnace, charged to the hopper and the bells and, finally in the furnace.
3. Non –decrepitating nature.
4. An ability to withstand mild reducing condition at lower temperature without breaking.

5. A good bulk reducibility so as to obtain closed equilibrium conditions between solid and gas phases in the stack.
6. Low swelling tendency during reduction.
7. A high softening temperature with a narrow temperature range of fusion.

Chemical properties

1. A high percentage of iron to gangue ratio.
2. A low percentage of silica, alumina and a low alumina to silica ratio.
3. Good overall chemistry of the burden to ensure adequate desulphurization of metal and absorption of coke ash in slag.
4. Good overall chemistry to ensure clean slag and metal separation at minimum temperature and free flow of both slag and metal.

In addition, sintering is also carried out to improve size grading and reducibility of iron ore concentrate to avoid wasting of fines, reduction of the quantity of coke used in the blast furnace and lastly to use up waste materials from blast furnace flue dust.

The quantity of sinter produced by the integrated blast furnace route has risen from 371.2mt in1982 to 422.7mt in 1994, accounting for 55.0% to 57.9% of total crude steel production. Therefore more than 50% of the total liquid iron production during this period was supplied via the blast furnace for which sinters remain the major iron feed stock. However, Pellets are gradually replacing sinters to a certain degree, depending on available local process, economic and environmental circumstances with the global

output of the two products in 1994 standing at 534.3mt and 224.7mt for sinter and pellet respectively (Madugu, 2001).

Iron ore sintering is a complex thermo-chemical process and the qualities of sinters being produced affect the blast furnace performances in terms of fuel consumption, smooth operation, and rate of production. (Nath et al., 2004). Presently, the proportion of sinters in the charge of most blast furnaces amounts to 90% of the total weight of charge. Recently, the use of sinters is gradually increasing as mines produce more dusty, complex and lean ores, which need to be ground to a very fine particle before beneficiation. The world trend for use of sinters in pig iron production via the conventional blast furnace (acid and basic) is given in Appendix 1.0. Ogg et al., (1977) observes that the production and use of sinter for pig iron and hot metal manufacture continues to grow in 90% of the world's steelmaking areas. This expansion is often faster than the growth of iron production, showing that the use of sinter in the blast furnace will continue to increase since the iron content of the ores to be sinter is generally rising and thereby lower the slag volume in the blast furnace.

1.1 Statement of problem

Agbaja ore deposit has an estimated reserve of about 2 billions (2×10^9) metric tonnes, containing high phosphorus (P_2O_5 = 1.5-2.14%) and low silica, because of this, the deposit is not suitable for pig iron production. Phosphorus exists in iron ores as phosphorus pentoxide (P_2O_5) and this cannot be reduced during beneficiation technique and agglomeration. Kudrin (1989) observes that the effects of the phosphorus on the machined iron properties and steel are enormous. In order to use Agbaja iron ore, it is

imperative to blend the ore with Itakpe iron ore with a reserve of about 200-300 million metric tonnes having low phosphorus (0.03%) and high silica to take care of the high phosphorus in Agbaja iron ore and also to provide large source of iron ore for sinter production.

1.2 Aims and Objectives of the Study

The main aim is to determine the optimum-blending ratio, the ratio at which the two ores, when blended will produce sinters with physical and chemical properties that are suitable for pig iron production via the blast furnace process. The results obtained will also be compared with the minimum standard specifications required of sinters for pig iron production via the blast furnace route.

1.3 Justification and Significance of the study

The Agbaja iron ore deposit exists in large quantity and it is very close to Ajaokuta. Because of high phosphorus associated with it, there is the need to intensify effort in order to find the means of utilizing the ore economically. One of such means/alternatives is by blending which is the main focus of this research work.

If this research is successful, it will find a solution to the use of Agbaja through blending with Itakpe iron ore for the production of sinters for Ajaokuta Steel Company. This will augment the source of raw material input for pig iron production at Ajaokuta Steel Company. Also the sinter to be produced could be exported as this will attract foreign exchange earning.

1.4 Limitations of the research

As a result of non-availability of some equipment, certain tests, like swelling index, hot compression strength and low temperature characteristics may not be carried out.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The bases, principles, concepts and objectives underlying this research work were introduced in chapter one. It has been pointed out that this study is concerned with the use of blends produced from two concentrates of Agbaja and Itakpe iron ores to produce sinters and then determine the optimum-blending ratio that will give sinters suitable for pig iron production. In this chapter, the aim is to provide a theoretical background then review researches that have been carried out in the field of sinter production and relate them to this research.

2.2 Nigerian Iron Ore Deposits

Iron ore deposits were first discovered in Nigeria as far back as 1904 in Itakpe. Several deposits have been discovered and are located in Kogi, Plateau, Bauchi, Borno, Kebbi, Enugu, Abia, Kaduna, Ondo, Kwara, Oyo, and Edo States. Most of the deposits belong to the hematite, magnetite, goethite, and siderite-goethite groups total. The estimated reserves of iron ores in Nigeria are in excess of over 3 billion (3×10^9) metric tonnes. Hence, the utilization of these deposits in iron and steel plants will reduce cost of importation, thereby saving our foreign exchange, improving our military defense, agriculture and providing employment opportunity (Oloche et al., 1996).

Some of the deposits already worked on are given in table 2.1

Table 2.1: Irons Ore Deposits in Nigeria with their reserves, iron and phosphorous content.

S/No	Deposit	Location	Estimated reserves (mt)	$\%P_2O_5$	%Fe
1	Itakpe	Kogi	200 -300	0.06	38-45
2	Oshokoshoko	Kogi	12-14	0.02	30-40
3	Ajabanoko	Kogi	60	0.01	37-43
4	Agbado-okudu	Kogi	60	0.02	43-54
5	Akoina	Kogi	Under investigation	-	41-47
6	Tajimi	Kogi	200	0.02	39-58
7	Ero	Kogi	-	-	-
8	Ebiya	Kogi	-	-	-
9	Obanaja	Kogi	-	-	-
10	Agbaja	Kogi	2 Billion	2.14	43-49
11	Kotokarfe	Kogi	850m	2.08	43-53
12	Bassa Nge (Egenji Ate)	Kogi	400	1.45	43-49
13	Kakun (Kabba)	Kogi	-	-	38-42
14	Ubo-Toso	Edo/Kogi	-	-	U.I
15	Akunu (Ikare)	Ondo	-	-	U.I
16	Kagara (Kubacha)	Kaduna	-	-	58-63
17	Muro	Plateau	3.8	0.056	25-38
18	Rishi	Bauchi	-	-	10-19
19	Ayiwawa	Bauchi	-	-	6-23
20	Karfe	Borno	-	-	34-45
21	Gamawa	Bauchi	-	0.02	40-45
22	Dakin Gari	Kebbi	-	-	27-30
23	Nsude	Enugu	40.6	0.58	47-50
24	Ameki/Ohafisa	Abia	-	-	30-40
25	Veketuwo	Plateau	-	-	40-50

(-) Means unavailable information

Source: Adeleye, (1964), Akande et al., (2004)

2.3 Agbaja Iron Ore Deposit. Reserve and Chemical compositions

The Oolitic iron stone deposits are located in the Lokoja confluence (6^0 45^0E, 7^0 47^0E). Covering an area of 400km^2, in Kogi state of Nigeria and 40km North of Ajaokuta Steel Plant. The Niger and Benue Rivers divide the deposit into three major areas (BRGM, 1983):

1. The Agbaja Mount Patti-Lokoja area (approximately 150Km^2) located west of River Niger with a deposit over 2 billions metric tones.
2. The Kotokarfe area (approximately 170Km^2) located North of the confluence.
3. The Bassa-Nge or Egeneja area (approximately 80km^2) located south East of the confluence.

2.3.1 Chemical Composition of Agbaja Iron Ore

Agbaja iron ore has been studied extensively by National Metallurgical Development Centres, Jos. Results of chemical analysis of borehole core samples are given in Table 2.2. The ore is rich in iron, phosphorus, alumina and silica contents while Sulphur is low

Table 2.2: Chemical composition of samples from Agbaja Iron Ore Deposit.

S/no	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	CaO	MgO	K_2O	MnO	P_2O_5	S
1	67.93	9.98	9.98	5.73	0.15	1.43	0.54	0.03	1.43	0.11
2	68.70	10.56	10.54	7.35	0.25	0.28	0.48	0.04	2.10	0.13
3	39.16	5.04	5.04	21.52	1.36	0.03	0.10	0.14	0.52	0.02
4	70.29	7.59	7.59	5.31	0.21	0.03	0.10	0.02	1.58	0.01
5	67.93	7.77	7.77	6.61	0.31	0.01	0.10	0.03	1.74	0.01
6	68.56	10.89	10.89	7.50	0.23	0.23	0.10	0.02	2.65	0.01
7	67.11	12.11	12.11	10.00	0.30	0.23	0.10	0.01	1.13	0.01
8	69.57	11.45	11.45	8.10	0.31	0.45	0.10	0.02	0.80	0.02
9	70.17	9.60	9.60	5.29	0.23	0.42	0.10	0.03	2.20	0.06
10	68.30	9.63	6.63	6.63	0.24	0.24	0.16	0.04	1.74	0.02

Source: Uwadiale and Hall (1985)

2.3.2 Itakpe Iron Ore Deposit, Reserve and Chemical Analysis

Itakpe Iron Ore occurs in Kogi State. The National Iron Ore Mining Project's (1990) report shows that the Ore deposit falls within the Ebira-Kabba-Jakura Metasedimentary Region in the North Central Part of Nigeria. The structure of Itakpe hill deposit continued to the Southern limb of the large Ajabanako anticline with endowing rocks and conformable ore layers striking sub Latitudinal southwestward at angles ranging from 40^0 to 80^0 with local complication like minor folds (National Steel Council, 1978).

The deposit extends approximately 3,000 meters in length, Umunnakwe (1985) and includes about 25 layers of ferruginous quartzite of which about 13 are economically mineable.

2.3.3 Chemistry and Mineralogy of Itakpe Iron Ore

National Iron Ore Mining Project Itakpe-Okene, assigned the deposit into layers-namely-Northern, Intermediate, Central and Southern layers respectively. The table 2.3 gives the index of Ore layers, average thickness and % Fe content.

Table 2.3: Elaborate Chemical Assays of Samples from various Layers of Itakpe Iron Ore Deposit.

Sample N	Fe_2O_3	Al_2O_3	SiO_2	CaO	MgO	P	S	TiO_2	MnO	LOI
C_1	27.37	0.39	39.39	0.01	0.01	1.28	0.02	0.03	0.20	1.09
C_2	26.63	0.62	44.02	0.01	0.01	1.25	0.07	0.01	0.21	0.09
C_4	44.75	0.76	29.02	0.01	0.01	0.51	1.03	0.01	0.21	0.68
NHN_2	34.21	0.63	18.16	0.01	0.01	1.39	0.05	0.04	0.10	0.62
S	47.49	0.66	-	0.01	0.01	0.07	0.03	-	-	-

Source: NMDC Jos l

Chemical analysis of the ore shows that Fe content varies from 24.41- 47.49%, averagely 35.95% Fe. Silica is high, while alumina, sulphur and phosphorus are low.

2.4.0 Fluxes

Fluxes are substances added during smelting to bring down the melting temperature of the gangue materials, reduce the viscosity of the slag and decrease the activity of silica to make them stable in the slag phase which is formed by the combination of gangue and the flux (Harold, 1971).

The main purpose of fluxes lies in slagging the gangue contained in ore, coke, ash and other components of the burden. Bytakin (1978) broadly classified fluxes into the followings:

2.4.1 Basic fluxes

These include calcium carbonate, either pure or with an admixture of some amount of magnesium carbonate. Basic fluxes are employed when the gangue is predominantly silica. A pure limestone is composed of calcium carbonate.

2.4.2 Aluminous Fluxes

These comprise of clay shales, bauxites and are used in melting low aluminous ore.

2.4.3 Acid fluxes

Acid fluxes are used in melting high aluminous ore; low-grade. Table 2.4 and 2.5 give some of the deposit of fluxes in Nigeria with their reserves and chemical compositions.

Table 2.4: Fluxes deposits in Nigeria and their reserves

S/no	State	Location	Reserve (Mt)
1	F.C.T	Burum Marble (Keffi)	4.85
2	Kogi	Kogi Etobe	131,000T
3	Kogi	Ubo marble (Okene south)	21.3
4	Kogi	Jakura marble	46.4
5	Kwarea	Elebu marble	U.I
6	Niger	Kwakuti marble	2.5
7	Oyo	Igbetti marble	49
8	Anambra	Nkalagu limestone	15.6
9	Bauchi	Ashaka limestone	3.1
10	Bauchi	Kanawa limestone	75,000T
11	Edo	Owan limestone	U.I
12	Benue	Makurdi-Agwuatashi limestone	U.I
13	Benue	Yandeu limestone	116
14	C/River	Mfamosing limestone	11.22

Key: U.I:- Unavailable information

Source: NMDC, Jos

Table 2.5: Typical Chemical compositions of some Fluxes found In Nigeria

		Borno	Kano
1	CaO	31.17	45.93
2	SiO_2	22.49	7.15
3	Al_2O_3	3.37	3.39
4	Fe_2O_3	1.71	1.89
5	MgO	0.52	0.89
6	TiO_2	0.32	0.15
7	P_2O_5	-	0.40
8	SO_3	0.10	0.07
9	L.O.I	32.98	39.16

Source: NMDC, Jos/RMRDC, Kaduna

2.5.0 Definition and Concept of Sintering

Ore dressing produces fine-grained iron ore concentrates which cannot be used directly as they are in the blast furnace because of the possibility of clogging of the blast furnace

stack. The fine Iron ore concentrates produced are then converted into lumpy materials of controlled physical and chemical properties called sinters. The process of converting fine particles to lumps of desired physical and chemical properties is called agglomeration. Agglomeration processes can be broadly classified into four (4) types namely: Sintering, pelletising, Briqueting and Nodulising Sintering and pelletising are the two most populous processes applied to iron ore concentrates for the purpose of preparing them for pig iron production (Gilchrist, 1982).

Sintering is defined by Linchewsky et al., (1983) as a process of agglomerating iron-ore fines, in order to impart certain physical and chemical properties through addition of fluxing, desulphurization and dearsenication addictives. This process involves fusion and diffusion and is conducted below the melting point of the mineral constituents in the ore.

In iron ore sintering the aim is always to produce a strong but porous agglomerate from a sandy uncompacted mass. Ventatachalam, (1982) recommended that sinters should maintain the permeability of the gases in the blast furnace and have control on the reducibility and softening characteristics of the charge.

2.6.0 Background of Sintering

Iron ore sintering is carried out by introducing mixture of iron bearing fines with solid fuel on a permeable grate. The iron ore concentrates are crushed and thoroughly mixed with blast furnace flue dust, fine coke breeze (3mm or less in size), and limestone. The mixture is then loaded in a sintering machine of a layer 200 – 350mm thick with an intensive flame source to ignite the fuel contained in the charge by an exhaust fan that is

located beneath the agglomeration charge air suction through the layer. The burning starts at the top of the charge and gradually proceeds downwards through the layer and ends at the gate of the machine. This burning of fuel raises the temperature in excess of 1100 – 1250^0C, which is sufficient to partially fuse the sinter charge grains. On completion, Linchevsky et al., (1993) observes that the layer becomes porous. Return sinter of about 25mm in size covers the grate in order to protect the bed.

The following features are characteristics of the sintering process:

i. The fuel burns without flame;

ii. The air sucks through a layer of red-hot agglomerate and cools down. It than heated itself to a temperature close to that of the sinter.

iii. The combustion gases give up their heat to the charge through a large contact area.

Sintering consists of the following stages.

i. Preparatory stage: this involves fuel firing of the charge surface and the down-drafted of the hot combustion gases. The moisture got out through evaporation.

ii. Burning: the fuel ignites and iron oxides partially reduce, the burning of the fuel commences and carbon burns to carbon monoxide.

iii. Cooling, the sintered material is cooled by down drafted cold air.

However, Wild, (1953) gave the basic problems involved in the processes as follows:

1. gas flow through beds of broken solid;

2. gas-solid heat transfer;
3. combustion of solid fuel;
4. chemical reaction: calcinations of carbonates reduction and oxidation of iron ores, formation of silicates and ferrite; and
5. Partial melting and resolidification of slag phase.

2.7.0 Reduction Reactions that occurred During Sintering

During sintering process, the following chemical reactions take place; Fe_2O_3 is converted to magnetite Fe_3O_4 in two ways

(i) $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$, ……..(1)

(ii) $6Fe_2O_3 \rightleftharpoons 4Fe_3O_4 + O_2$……....(2)

equation (2) in turn, may be converted to FeO by burning of coke.

$$Fe_3O_4 + CO = 3FeO + CO_2.$$

At high temperature, the magnetite interacts with silica.

$$2Fe_3O_4 + 3SiO_2 + 2C = 3(2FeO.SiO_2) + 2CO \text{……(3)}$$

The formed fayalite 2 $FeO.SiO_2$ melts at 1265^0C. Added limestone yields Ferro calcium (CaO)x. FeO_2-$_X$.SiO_2 which melt at 1130^0C and alongside with other low-melting formations weld together high-melting particles.

During sintering, about 95% of the sulphur contained in the original ore material is removed as a result of the following sulphide and sulphate dissociation reactions.

$$2FeS_2 \rightarrow 2FeS + S_2 \text{……....(4)}$$

$$2FeS + 3.5O_2 = Fe_2O_3 + 2SO_2 \text{ …….....(5)}$$

$$3FeS+5O_2=Fe_3O_4+ 2SO_2 \text{ ……....(6)}$$

$$CaSO_4 \rightleftharpoons CaO + SO_3 \text{ …….....…….....(7)}$$

$$BaSO_4 \rightleftharpoons BaO + SO_3 \text{ …….……(8)}$$

However, the following conditions favour the removal of sulphur

i. a good permeability of the charge

ii. a thinner layer of the charge

iii. a fine grade of the ores

iv. a higher iron content and

v. a low content of slag – forming components in raw ore. Sintering cannot eliminate phosphorus. It decreases arsenic content by 20%. (Linchevsky et al., 1983).

2.8.0 Process Variables during Sintering

During heating process, there are certain factors which should be properly adjusted for obtaining effective sintering. The variables of the sintering process are broadly as follows:

i. bed permeability as decided by the particle size and shapes of the mix.

ii. thickness of the bed

iii total volume of air blast drawn through the bed for it's sintering.

iv. rate of blast drawn through the bed during sintering

v amount and quality of solid fuel incorporated in the charge

VI amount and type of carbonates present in the charge

vii amount of moisture in the charge

viii nature of ore fines e.g. its chemical composition

ix any non-uniform in the bed composition or in the process of sintering.

2.8.1 Roles of sinter returns in sintering

The roles of sinter returns during sinter production are: It

1. Makes the charge more loose or soft,
2. Increase the gas permeability of charge and
3. Improves the conditions of sintering process.

2.8.2 Positive effect of sinter return on gas permeability

1. The grains of sinter are soft and have porous surface. Because of this, the air passes through it with less resistance in comparison to the grains of ore.
2. Sinter return which is uniformly distributed in the charge prevents the charge being more dense during its loading to the sinter pot. No direct contact with the burning zone.
3. It also prevents the charge from being more pressed by the vacuum action.

2.9 Types of Sinters

Three different types of sinters are being produced depending upon the extent of addition of flux in the mix and these are

1. **Acid Sinters:** The sinter mix does not contain flux at all. flux is added in the furnace separately. The production of this types is of declining and most modern practices produce self-fluxing or super-fluxed sinter.
2. **Flux sinters:** the amount of flux added in the mix is such that the basicity of the mix is equal to that of the slag to the produced in the furnace. Separate addition of flux would be required only in proportion to the amount of natural lumpy ore charge in the furnace. This is also fast declining in preference to super-fluxed sinter.
3. **Super-fluxed sinters:** the entire amount of flux that is required to be charged in the furnace when run on 100% natural ore charge is added in the mix. The basicity of the mix would be obviously more than that of the slag in the furnace. If super fluxed is used, there will be no separate flux required.

The use of flux in the sinter raises greatly the efficiency of the blast furnace smelting. So if charged in place of a common agglomerate, it reduces the amount of limestone 4.5times and coke by 11% while furnace output is increased by 12% (Linchevsky et al., 1983)

2.10 Desired Qualities of sinters

The power of sintering was originally developed merely to agglomerate the iron ore fines. The beneficial effects of sinter as a blast furnace burden were realized; the physical properties and chemical constitution of sinter can be examined more closely.

Linchevsky et al., (1983) said that a good sinter must be hard, porous and readily reducible. Its braking strength or wear resistance must be satisfied. That is, a sample of 20kg in a closed steel drum and rotating it for a specified time. The strength is guided by a quantity of formed fines: the lump 0 – 25mm across must not exceed 25%. The standard (qualities physical and chemical properties) desired of sinters for use in pig iron production are given in tables 2.6and 2.7.

From the table 2.6, the lower the Abrasion, Reduction Decrepitating index values and the higher the shatter, Tumbler and Reduction index values the better the sinters

In table 2.7, the chemical composition of the sinters produced must be within these value in order to meet the blast furnace specifications.

Table2.6: Standard Physical Properties Desired of Good sinters

Expt No	Abrasion index value (AIV)	Shatter index values (SIV)	Tumbler Index value (TIV)	Reducibility index value (RIV)	Reduction decrepitation index value (RDIV)
1	4.00	90.50	81.00	74.30	29.50
2	4.60	93.60	80.34	72.60	31.50
3	4.30	94.30	81.50	73.60	30.61
4	4.20	89.50	79.60	72.50	33.50
5	4.11	90.44	78.50	71.61	32.50
6	5.10	88.40	77.60	76.80	32.50
7	5.00	81.30	76.90	77.60	28.95
8	5.50	83.60	82.50	78.30	29.61
9	4.10	91.50	79.60	79.50	31.61
10	4.81	79.80	78.60	78.11	32.50
11	5.01	78.40	77.88	76.33	33.40
12	4.79	88.60	81.50	69.95	35.50
13	5.23	92.44	82.11	68.67	34.50
14	5.25	77.50	80.30	75.11	33.61
15	4.22	76.90	80.50	74.39	35.60

Source: Ispat Metallic India Ltd, Ajaokuta Steel Company.

Table 2.7: Standard chemical composition of good sinters

Expt No	Fe	CaO	Al_2O_3	SiO_2	P	CaO/SiO_2
1	66.43	14.11	1.46	5.31	0.040	2.61
2	64.31	14.50	1.73	6.10	0.051	2.51
3	63.41	13.61	1.99	6.34	0.062	2.43
4	62.90	13.72	2.11	5.19	0.071	2.31
5	65.41	12.88	2.16	7.31	0.088	2.20
6	64.20	13.01	2.00	7.00	0.066	2.32
7	63.39	14.02	3.11	6.99	0.053	2.55
8	65.70	14.66	2.88	6.81	0.031	2.70
9	65.61	10.67	2,76	5.63	0.021	2.00
10	65.51	11.90	2.34	5.21	0.015	2.61
11	62.91	11.96	2.77	5.11	0.022	2.91
12	63.41	12.88	2.51	5.44	0.060	2.82
13	64.21	13.66	2.34	5.32	0.075	2.03
14	64.36	12.41	3.63	5.12	0.077	2.33
15	66.01	14.55	2.14	5.15	0.081	2.41
16	65.41	13.33	2.19	5.18	0.078	2.13
17	64.01	12.66	3.14	5.21	0.084	2.14
18	63.11	14.05	3.33	5.33	0.099	2.67
19	62.88	14.05	3.04	5.44	0.088	2.57
20	65.66	13.45	2.96	5.61	0.033	2.48

Source: Ispat Metallic India Ltd, Ajaokuta Steel Company.

2.11 Comparison between sinters and pellets

Sintering is preferred if the ore size is – 10mm + 100mesh and if it is -100 mesh pelletizing is adopted. Pelletizing requires ultra fines of over 75% of – 325mesh. Porosity

of sinter is 1-18% and that of pellets is 20-30%. The shape of pellets is near spherical and hence bulk permeability of the burden is much better than that of sinter, which is non-uniform in shape. The installation cost of a pelletizing plant is 30-40% more than that of sintering plant of an equal size. The operating cost of sintering is less than that of pelletizing. Almost 50% of the cost of sinter comes from fuel used for sintering.

Sinter fines and pellets fines are equally detrimental and should be eliminated from the charge to ensure better performance of the furnaces. Use of pellet burden reduces hanging, which is often observed if a high proportion of sinter is used. The use of pellets saves coke by 25kg/t and the productivity by 15%. Because of the degradation, during transportation, the sinter therefore has to be produced thereby the blast furnace pellets can be carried over a long distance without appreciable degradation.

2.12 Charge Calculations for sinter production

The charge usually prepared for sinter production has the following approximate percentage compositions given in Table 2.8.

Table 2.8: Recommended composition of charge for sinter production

	Range	Average
Iron ore concentrate(0-2mm)	40-50	45
Limestone (0-2mm)	15-20	17.5
Sinter return (0-30mm)	20-30	25
Coke breeze (0.1-3.0mm)	4-6	5
Moisture	6-9	7.5
Total		100%

source: Linchevsky et al., (1982) and Venkachalam et al., (1982)

2.13 Mechanisms and Kinetics of reduction of blast furnace burden

According to Baik, iron ore oxides are reduced from a higher oxide to a lower one and to metal as follows:

$$Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow FeO \longrightarrow Fe \quad \text{.....(9)}$$

In an elementary cell of crystal, the process of reduction proceeds by instantaneous transformation of crystal lattice. Within an ore lump (sinter or pellets) it occurs by gradual removal of oxygen from the whole mass of a lump.

Fe_2O_3 is a weak formation. At 383K it changes to Fe_3O_4 even in the air, without reducing atmosphere. In the reducing atmosphere at the temperature below 843K, ferrous oxide is unstable and the reduction proceeds as follows:

$$Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow Fe \quad \text{.....(10)}$$

In the blast furnace, there are two gaseous reductants: Carbon monoxide – a product of incomplete combustion of coke carbon of the tuyeres and hydrogen, which is a product of blast-moisture decomposition, or hydrogen containing additional fuels (natural gas). Thermodynamically, the equilibrium reactions of iron oxides with the carbon oxide and hydrogen are given by Khomic et al., (1978) as follows

a. $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2 + 137.112M_J$; .....(11)

b. $Fe_3O_4 + Mco \quad 3FeO \rightleftharpoons + CO_2 + (m\text{-}1)\ CO - 20.88M_J$; .....(12)

c. $FeO + nCO \rightleftharpoons Fe + CO_2 + (n\text{-}1)\ CO + 113.6M_J$; .....(13)

d. $3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O - 21.8M_J$ .....(14)

e. $Fe_3O_4 + m' H_2 \rightleftharpoons 3FeO + H_2O + (m^I - 1)\ H_2 - 62.17M_J$ .....(15)

f. $FeO + n' H_2 \rightleftharpoons Fe + H_2O + (n^I - 1)\ H_2 - 27.7M_J$ .....(16)

Reduction by carbon monoxide and hydrogen are similar and differ only with the heat involved.

All the reactions, except (11) and (14) need excess of reductant to proceed to the right hand side as against the stochiometric ratios

The point is that the reactions (11) and (14) are necessary, i.e. in the atmosphere consisting of pure CO_2 and H_2O, Fe_3O_4 is not oxidize to Fe_2O_3 while the reactions (12), (13), (15) and (16) are reversible: at definite temperatures and concentrations, they proceed towards the formation of higher oxides. Therefore, it is necessary to have certain excess of reductants above the products of reactions for the process of reduction proceeding (depending upon temperature).

In other words, in each reversible reaction we can find for a preset temperature, such a ratio of the redundant to its oxide, in iron oxide and the products of its reduction are in the state of equilibriums in figures 2.1, 2.2 and 2.3.

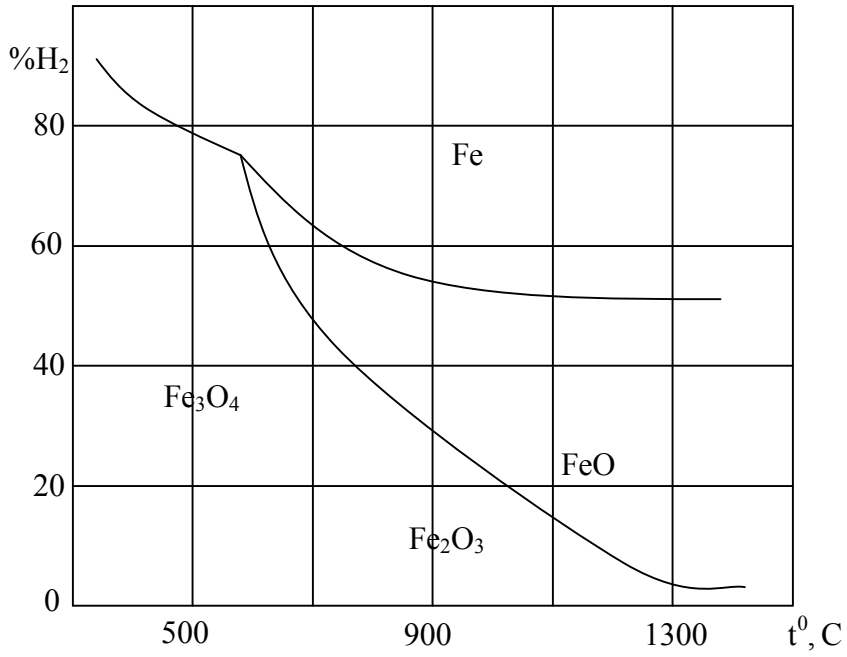


Fig 2..1: Equilibrum diagram Fe-O-H

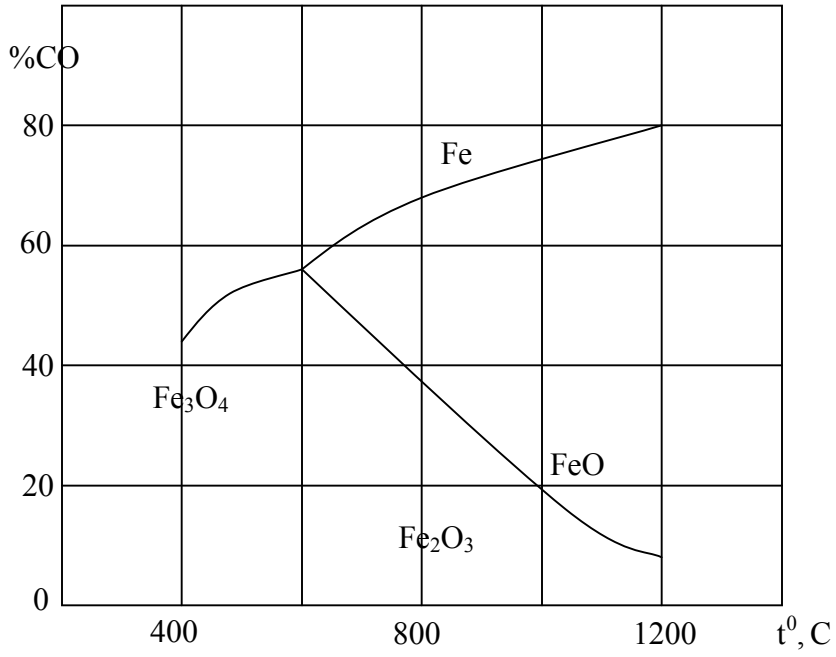


Fig 2.2: Equilibrum diagram Fe-O-C

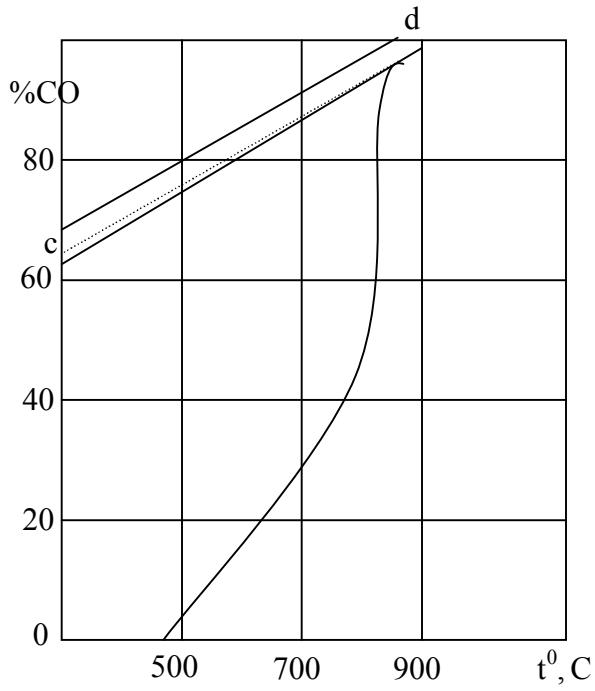


Fig 2.3: Comparison of gas composition in blast furnace

From these diagrams, it is possible to determine the direction in which the reaction will proceed at a preset temperature and a predetermined composition of the gaseous phase.

In reducing Fe_3O_4 to FeO by both the reductants, the content of the reducdant in the equilibrium mixture is decreased as the temperature is increased (the equilibrium curve goes to the right and downwards). It is possible to determine from the diagrams the value of coefficient of m, n, m^1 and n^1 in the above reactions. For instance, the equilibrium gas for the reaction FeO + nCO at 800^0C consists of 63% Co and 37% of CO_2. Consequently, to make the reaction with the formation of metallic iron, it is necessary that:

$$CO:CO_2 = >63:37 => 1.7 \quad \text{.....(17)}$$

i.e. (n-1):1>1.7 from where n>2.7. At higher temperature, n increases as observed by (Khomich et al., 1978).

For a comparison of the equilibrium conditions for reduction with carbon monoxide and hydrogen, it is necessary to superimpose the two diagrams. The superimposing shows that the diagrams intersect each other at the temperature 810^0C. Below this temperature, the hydrogen curves are above the CO curves while above the temperature, they are situated vice versa. Below 810^0 only carbon monoxide is used and above that temperature, hydrogen is used. In other words, below 810^0C m′>m and n′>n and above 810^0C m′<m and n′<n. At 810^0C m′=m and n′=n.

The reaction of Bell-Buduar is well developed in the blast furnace depending upon the temperature and pressure.

$$2CO \leftrightarrow C + CO_2 \pm 16.5\ MJ \quad \text{.....(18)}$$

The equilibrium curves of this reaction and actual compositions of gases in the blast furnace at various pressures (curves of the c-d) are represented in figure. 2.3. It is obvious that at high temperatures (about 900^0C) actual gas composition in the blast furnace is close to an equilibrium one (about 100% CO). This is ensured by a high rate of the reverse reaction (of Buduar). $C + CO_{2]} = 2CO - 589.812MJ$ is obvious that the Bell's reaction is notably accelerated in the presence of a freshly reduced sponge iron.

At the top of the furnace the flue gas at 300^0C contains 15% CO_2 and 25% CO, which is the term of 100% CO_2 + CO makes up 63% CO and 37% CO_2. That is, the gas at the furnace top is close to an equilibrium one for the reaction FeO +CO(point C in the diagram). At 1000^0C (point d) consists of 100% CO, but it does not mean that the reaction below cannot proceed:

$$FeO + CO \rightarrow Fe + CO_2, \quad \text{.....(19)}$$

The first stage of the reaction of direct reduction. The second stage is:

$$CO_2 + C \rightarrow 2CO \quad \text{.....(20)}$$

The summary reaction is as follows:

$FeO + CO \rightarrow Fe + CO_2$, - 15.19 MJ……………………………(21)

Hydrogen, apart from its duty of a reducing agent in the blast furnace, acts as a carrier of oxygen in the reduction reactions with Carbon and its monoxide:

1. $FeO + H_2 \rightarrow Fe + H_2O$ – 27.6MJ………………………...(22)
2. $H_2O + CO \rightarrow H_2 + CO_2$ + 41.25MJ…………………….(23)

Summary:

3. $FeO + CO \rightarrow Fe + CO_2$ + 13.58MJ……………………...(24)

Or

1. $FeO + H_2 \rightarrow Fe + H_2O$ – 27.67MJ…………………..........(25)
2. $H_2O + C \rightarrow H_2O + CO$ + 124.27MJ……..………………(26)

Summary:

3. $FeO + C \rightarrow Fe + CO$ + 151.94 MJ…………..……………(27)

Source: Khomich et al., (1979)

CHAPTER THREE

3.0 EXPERIMENTAL TECHNIQUES

3.1 MATERIALS

Fifteen kilograms (15kg) of the concentrates with twelve kilograms (12kg) of calcined lime and coke breeze and iron chips were used for this work. The chemical compositions of these raw materials are given in table 3.1. These materials were sourced from National Metallurgical Development Centre Jos and Ajaokuta Steel Company. The sinters were produced at the National Metallurgical Development Center(NMDC) Jos while the physical and chemical properties of the produced sinters were determined at NMDC and Ajaokuta Steel Company respectively.

Table 3.1: Chemical analyses of the Raw Materials Used.

Constituents	Tot Fe	Fe^{++}	SiO_2	CaO	Al_2O_3	TiO_2	MgO	P	Mn	S	Co_2	H_2O	C	Mois ture	L.OI
Agbaja concentrate	58.02	8.03	10.89	1.21	9.60	0.37	0.54	1.43	0.18	0.12	-	-	-	-	10.71
Itakpe cons	66.28	9.63	5.50	9.00	1.00	0.43	1.40	0.05	0.11	0.012	0.055	0.04	-	-	16.41
Calcined lime (flux)	0.49	0.00	1.95	53.35	0.60	0.06	0.50	0.020	0.04	0.020	41.20	0.42	-	-	1.90
Coke breeze (fuel)	2.87	0.00	6.66	1.35	3.62	0.11	0.26	0.090	0.04	1.46	0.00	0.00	76.63	6.40	0.50

source: ASCL & NDMC, JOS

3.2 Methods

3.2.1 Charge calculation

In this experiment, the total moisture fluxed sinter to be charge into sinter pot grate will be 4.00kg. The calculations are;

i) Concentrates (Iron ores) = $\frac{45}{100}$ x 4.00 = 1.800kg

ii) Limestone = $\frac{17.5}{100}$ x 4.00 = 0.700kg

iii) Coke breeze = $\frac{5}{100}$ x 4.00 = 0.200kg

iv) Moisture = $\frac{7.5}{100}$ x 4.00 = 0.300kg = 0.300L

v) Sinter return = $\frac{25}{100}$ x 4.00 = 1.00kg

Total **4.00kg**

vi) Bed layer 0.50

vii) Top layer 0.03

Total **4.53**

Ix Left over Total weight charge = 4.53kg

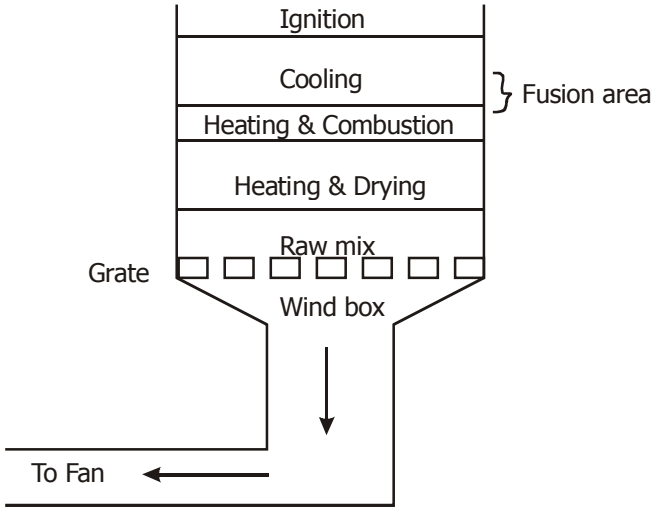
Based on the charged calculations carried out above, table 3.2 shows the blend rations of materials used.

Table 3.2: The blending ratios of materials

Expt No	% Agbaja	% Itakpe	Kg Conce -ntrate	Kg Agbaja	Kg Itakpe	Kg Lim e	Kg Coke	Liter Moist- ure	Kg R. Sinter
T_1	100	-	1.80	1.80	-	0.70	0.20	0.30	1.00
T_2	-	100	1.80	-	1.80	0.70	0.20	0.30	1.00
1	10	90	1.80	0.18	1.62	0.70	0.20	0.30	1.00
2	15	85	1.80	0.27	1.53	0.70	0.20	0.30	1.00
3	20	80	1.80	0.36	1.44	0.70	0.20	0.30	1.00
4	25	75	1.80	0.45	1.35	0.70	0.20	0.30	1.00
5	30	70	1.80	0.54	1.26	0.70	0.20	0.30	1.00
6	35	65	1.80	0.63	1.17	0.70	0.20	0.30	1.00
7	40	60	1.80	0.72	1.08	0.70	0.20	0.30	1.00
8	50	50	1.80	0.90	0.90	0.70	0.20	0.30	1.00
9	60	40	1.80	1.08	0.72	0.70	0.20	0.30	1.00
10	70	30	1.80	1.26	0.54	0.70	0.20	0.30	1.00

The materials were taken as calculated and given in table 3.1 and mixed thoroughly. The coarse material (iron chips) was used because of unavailability of returned sinter initially. The mixture was spread uniformly on the grate so as to avoid hindering of the gas flow. The thickness of the coke breeze is about 2-3mm over the charge (top layer) to ensure uniform ignition conditions. After igniting, a constant sintering time of 33 minutes was allowed with 2 minutes for ignition, 28 minutes for sintering and 3 minutes for on-strand cooling. The readings of the exit gas temperature were taken and the fall in the temperature from the peak indicates the end of sintering operation. The sintering temperature measured using a thermocouple is approximately 1200^0C.

Figure 3.1 is the schematic diagram of the sinter pot with details of phases involved during sintering.



Source: Ajaokuta steeel company

The laboratory testing procedures used at Ajaokuta steel company to determine abrasion, shatter, tumbler, reducibility and reduction decrepitation index values of the sinter produced are given below;

3.2.2 Determination of Abrasion Index Value (AIV)

About three kilograms (3kg) of sinter produced sample of size +25, -40mm was weighed. The weighed sample was taken in a standard drum of speed 25 revolution per min (rpm). The drum was rotated for 200 revolutions (rotations). After the rotations, the sample was taken from the drum and screened in a 6.3mm size. Figure 3.1 shows the drum. The abrasion index value was calculated as following.

$$\text{Abrasion index}(\%) = \frac{\text{weight of sample (-6.3mm size)}}{\text{Total weight of the sample taken (3kg)}} \times \frac{100}{1} \quad \text{.....(28)}$$

3.2.3 Determination of Shatter Index Value (SIV)

Two kilograms (2kg) of product sinter sample of size +25, -40mm size was weighed. The sample was dropped from a height of two metres (2m). The experiment was repeated for four times. The material was then screened and the undersize of 5mm was weighed. The shatter index value was then calculated as follows:

$$\text{Shatter index (\%)} = \frac{\text{weight of sample (+5mm size)}}{\text{Total weight of the sample taken (2kg)}} \times \frac{100}{1} \quad \ldots\ldots\ldots(29)$$

3.2.4 Determination of Tumbler Index Value (TIV)

The procedure has been described in 3.4.0 except that the weighed of the sample to be screened was +6.3mm size instead of -6.3mm size.

$$\text{Tumbler index value (\%)} = \frac{\text{weight of sample (+6.3mm size)}}{\text{Total weight of the sample taken (3kg)}} \times \frac{100}{1} \quad \ldots\ldots\ldots(30)$$

3.2.5 Determination of Reducibility Index Value (RIV)

The sample was dried in a hot oven at temperature of 110^0C to get ride of the moisture content. About 500gm of product sinter sample size +25, -40mm size was then weighed. The weighed sample was put in a reacting vessel made of in connel – 600-grade steel. The vessel was then pushed in an electric muffle furnace and maintained at 900^0C. The mixed gas of N_2 and CO in the ratio 70:30 was passed for 3 hours.

The sample was cooled down to room temperature by passing N_2 gas. The reacted sample was removed and weighed and calculated the percentage weight loss as

Reducibility index value (RIV)

$$= \frac{\text{Weight loss}}{\text{Fe(t)} - \text{FeO} \times 48/112 + \text{FeO} \times \frac{16}{50}} \times \frac{100}{1} \quad \text{.....(31)}$$

3.2.6 Determination of Reduction Decrepitation Index Value (RDIV)

The reduction decrepitation index value procedure was the same ass in reducibility index value (RI) except after cooling the sample down to room temperature, the sample was taken in a small tumbling drum at 30rpm for 30 minutes. The sample was screened on 6.3mm and 3.15 screens respectively. RDI was then calculated as follows:

Reduction decrepitation index value (RDI)

$$= \frac{\text{Weight of sample (-3.15mm size)}}{\text{Total weight of the sample taken (500gm)}} \times \frac{100}{1} \quad \text{.....(32)}$$

3.2.7 Determination of Chemical Composition of Sinters

An important single factor that affects the output and efficiency of a blast furnace is the quantity of the materials charged into the furnace. Because of this, it becomes necessary to carry out chemical analysis on each of the sinter produced from the blend in order to understand the physical chemistry of the sinters. The amount of individual elements/compounds determined are %Fe, %SiO_2, % Al_2O_3, %P, %CaO and the basicity of the sinter. The chemical analysis was carried out at Ajaokuta Steel Company.

3.2.8 Determination of Phosphorous content of the blends by calculation

Phosphorus content in the blend was calculated theoretically as follows:

Given: Agbaja P_2O_5 = 1.54 percentage

Itakpe P_2O_5 = 0.06 percentage

Total %P in the blend = $\dfrac{x \times \dfrac{P_2}{P_2O_5} \times 1.54 + y \times \dfrac{P_2}{P_2O_5} \times 0.06}{x + y}$

where x and y are the ratios of Agbaja and Itakpe, iron ore concentrates respectively.

$\therefore \quad \dfrac{\dfrac{P_2}{P_2O_5}(x \times 1.54 + y \times 0.06)}{x + y}$

Ratio of phosphorus-to-phosphorus pentaoxide

$= \dfrac{P_2}{P_2O_5} = \dfrac{31x2}{(31x2) + (16x5)} = \dfrac{62}{142} = 0.4366$

1. %P in 10:90 = $\dfrac{0.4366(10x1.54x90x0.06)}{100} = 0.090$

2. % P in 15: 85 = $\dfrac{0.4366(15x1.54x85x0.06)}{100} = 0.123$

3. % P in 20:80 = $\dfrac{0.4366(20x1.54x80x0.06)}{100} = 0.155$

4. % P in 25:75 = $\dfrac{0.4366(25x1.54x75x0.06)}{100} = 0.187$

5. % P in 30 : 70 = $\dfrac{0.4366(30x1.54x70x0.06)}{100} = 0.220$

6. % P in 35:65 = $\dfrac{0.4366(35x1.54x65x0.06)}{100} = 0.252$

7. % P in 40:60 = $\dfrac{0.4366(40x1.54x60x0.06)}{100} = 0.284$

8. % P in 50:50 = $\dfrac{0.4366(40x1.54x50x0.06)}{100} = 0.349$

9. % P in 60:40 $\frac{0.4366(60x1.54x40x0.06)}{100} = 0.413$

10. % P in 70:30 = $\frac{0.4366(70x1.54x30x0.06)}{100} = 0.487$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The results of the tests and analysis carried out in this work are presented in Tables 4.1 to 4.6 and Figures 4.1 to 4.6. The followings abbreviations are used in the course of discussing the results.

AIV - Abrasion Index Value

SIV - Shatter Index Value

TIV - Tumbler Index Value

RIV - Reducibility index value

RIDV - Reduction Decrepitation Index Value

CC - Chemical Composition

Table 4.1: The variation of Abrasion Index Values with blend ratio of the produced sinters

Experiment No	Agbaja to Itakpe Ratios (%)	Calculated (AI%)	Blast furnace Requirement(%)
1	10:90	4.50	4.00 – 4.80
2	15:85	4.90	4.00 – 4.80
3	20:80	5.00	4.00 – 4.80
4	25:75	5.20	4.00 – 4.80
5	30:70	5.60	4.00 – 4.80
6	35:65	6.00	4.00 – 4.80
7	40:60	6.60	4.00 – 4.80
8	50:50	7.40	4.00 – 4.80
9	60:40	9.50	4.00 – 4.80
10	70:30	10.50	4.00 – 4.80
	Average	6.50	4.75

Table 4.2: The variation of Shatter-Index Value (SIV) with blend ratio of the produced sinters

Experiment No	Agbaja to Itakpe Ratios (%)	Calculated (SI%)	Blast Furnace requirement(%)
1	10:90	90.00	80.00 – 93.50
2	15:85	88.00	80.00 – 93.50
3	20:80	87.00	80.00 – 93.50
4	25:75	79.80	80.00 – 93.50
5	30:70	70.60	80.00 – 93.50
6	35:65	65.50	80.00 – 93.50
7	40:60	63.80	80.00 – 93.50
8	50:50	50.60	80.00 – 93.50
9	60:40	56.60	80.00 – 93.50
10	70:30	51.30	80.00 – 93.50
	Average	70.49	85.00

Table 4.3: The variation of Tumbler Index Values (TIV) with blend ratio of the produced sinters

Experiment No	Blends (Agbaja:Itakpe) %	TIV obtained (%)	Blast furnace Requirement(%)
1	10:90	79.00	77.00 – 80.00
2	15:85	77.30	77.00 – 80.00
3	20:80	74.40	77.00 – 80.00
4	25:75	74.20	77.00 – 80.00
5	30:70	70.80	77.00 – 80.00
6	35:65	68.60	77.00 – 80.00
7	40:60	68.70	77.00 – 80.00
8	50:50	65.60	77.00 – 80.00
9	60:40	64.00	77.00 – 80.00
10	70:30	62.50	77.00 – 80.00
	Average	70.28	77.00 – 80.00

Table 4.4: The variation of Reducibility Index Values with blend ratio of the produced sinters

Experiment No	Blends (Agbaja:Itakpe) %	RIV obtained (%)	Blast furnace requirement (%)
1	10:90	73.00	70.00 – 79.00
2	15:85	72.00	70.00 – 79.00
3	20:80	68.00	70.00 – 79.00
4	25:75	67.00	70.00 – 79.00
5	30:70	65.00	70.00 – 79.00
6	35:65	60.00	70.00 – 79.00
7	40:60	58.00	70.00 – 79.00
8	50:50	56.00	70.00 – 79.00
9	60:40	55.50	70.00 – 79.00
10	70:30	54.00	70.00 – 79.00
	Average	62.51	

Table 4.5: The variation of Reduction Decrepitation Index Values with blend ratio of the produced sinters

Experiment No	Blends (Agbaja:Itakpe) %	RDIV obtained (%)	Blast furnace Requirement(%)
1	10:90	33.00	29.00 – 35.00
2	15:85	34.50	29.00 – 35.00
3	20:80	35.20	29.00 – 35.00
4	25:75	36.20	29.00 – 35.00
5	30:70	38.00	29.00 – 35.00
6	35:65	38.30	29.00 – 35.00
7	40:60	39.60	29.00 – 35.00
8	50:50	40.90	29.00 – 35.00
9	60:40	42.00	29.00 – 35.00
10	70:30	43.60	29.00 – 35.00

Table 4.6: Chemical Analysis of the produced sinters

Expt. No	Blends	Fe	CaO	Al_2O_3	SiO_2	P	Cao/SiO_2
1	Agbaja 100	-	-	-	-	-	-
2	Itakpe 100	66.28	13.69	1.32	5.25	0.03	2.60
3	10:90	65.45	13.59	1.98	5.61	0.09	2.42
4	15:85	65.04	12.95	2.20	5.90	0.12	3.19
5	20:80	64.61	12.70	2.38	6.01	0.15	2.11
6	25:75	64.21	12.65	2.69	6.22	0.18	2.03
7	30:70	63.80	12.60	3.01	6.73	0.21	1.87
8	35:65	63.39	12.51	3.21	6.93	0.24	1.81
9	40:60	62.97	12.03	3.24	7.14	0.28	1.68
10	50:50	62.56	11.85	3.63	7.34	0.34	1.61
11	60:40	62.15	11.76	3.94	7.55	0.40	1.56
12	70:30	61.32	10.34	4.12	7.86	0.41	1.32
	average	63.80	12.42	2.88	6.59	0.22	1.93

4.2 Discussion

4.2.1 Abrasion Index Values (AIV)

The results of the variation of the abrasion index with blend ratio are presented in Table 4.1 and Figure 4.1 respectively. From these results it can be seen that the abrasion index values increases as the ratio of Agbaja iron ore concentrate in the blend increases. This increase is probably due to the texture of the Agbaja iron ore (liberation size of 5μm) resulting in the production of much finer sinters as its proportion increases in the sinters. The finer sinters produced resulted in the assimilation of iron oxide and increase in the recrystallization of secondary phases (Wegman, 1984). However, some of the values obtained for the blends are within the recommended range for blast furnace requirements of 4.00 – 4.80. Also the blend with the ratio of 10% to 90% Agbaja to Itakpe has a minimum value of abrasion index is the most suitable because the lower the abrasion index value, the stronger the ability of the sinter to withstand degradation during movement in plant and in the furnace.

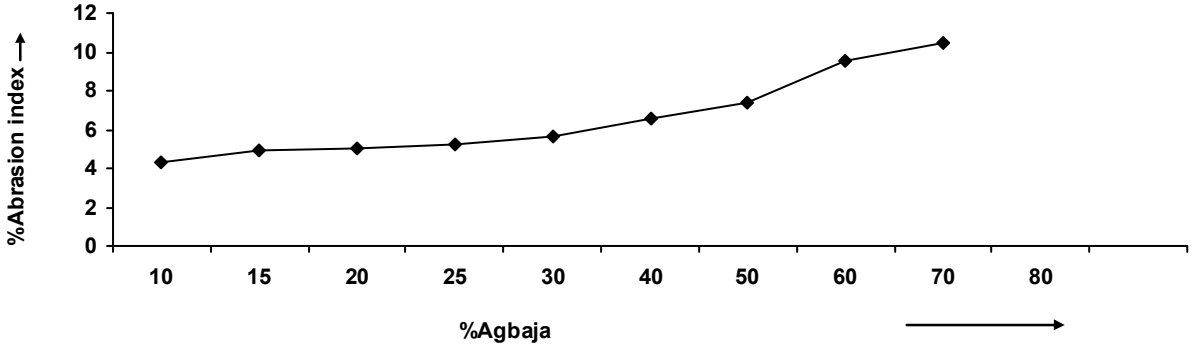


Fig 4.1: Variation of Abrasion index with blend ratio

4.2.2 Shatter Index Values (SIV)

The results of the variation of the shatter index with blend ratio are presented in Table 4.2 and Figure 4.2 respectively. From these results it can be seen that the shatter index values decrease with increase in the ratio of Agbaja iron ore concentrate in the blend. The decrease in the values may be probably due to formation and distribution of calcium silicate in iron bearing matrix phases as observed by (Tupkary et al., 1998).

Shatter index is a measure of the resistance of the sinter to impact and is an indication of the degree of fracture the sinter is likely to undergo during charging into the blast furnace.

10 – 15% Agbaja iron ore concentrate in the blends has met the minimum requirements for shatter index and is within the specified range of 80.00 – 93.50. However, the higher the shatter index value, the stronger the ability of sinters to withstand impact during movement in the furnace. It can be inferred that the 10% of Agbaja gave the best result from the Table 4.2 and reduced risk of fracture during charging into the blast furnace.

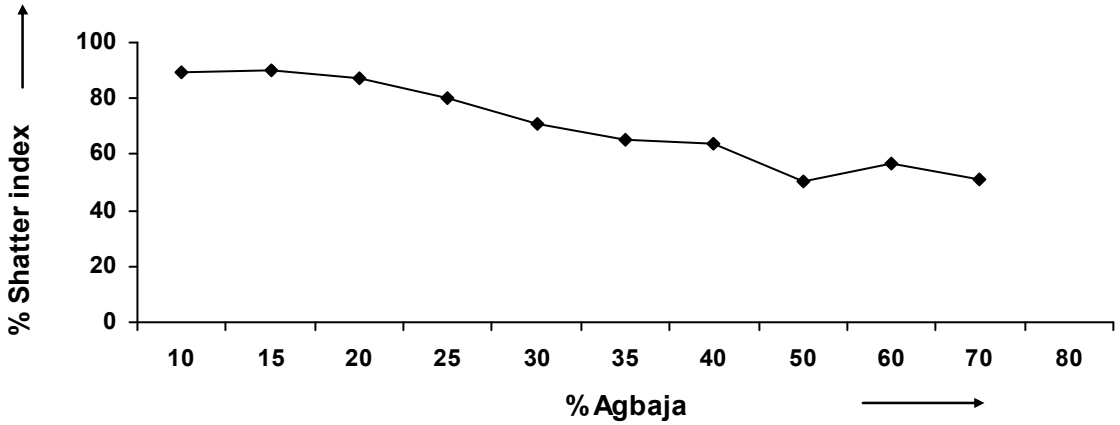


Fig 4.2: Variation of shatter index with blend ratio

4.2.3 Tumbler Index Values (TIV)

The tumbler index is a measure of the resistance of sinter to degradation from a combination of impact and abrasive forces. It also measures the breakage ability and the abradability of the sinters.

The results are presented in Table 4.3 and figure 4.3, the tumbler values decrease as the ratio of Agbaja iron ore concentrate was increased progressively. It may be probably due to weak and low porous sinters produce as a result of the inability of hematite to transform to magnetite instead precipitation of wustite occurred. From the results obtained, it can be seen that blends with 10-15% Agbaja have the highest values of tumbler index which are within the specified range of 77.00 - 88.00 as observed by Sofremiines, (2001). Higher the tumbler index value means better ability of the sinter to withstand disintegration during storage in the bins and also to bear the weights of other materials in the blast furnace without crushing

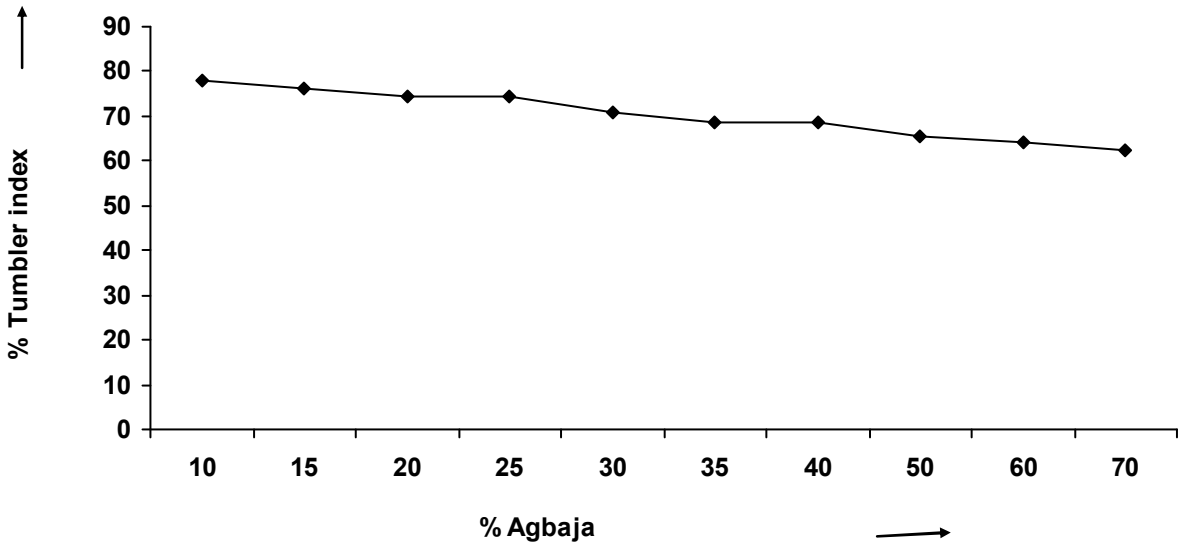


Fig 4.3: Variation of Tumbler index with blend ratio

4.2.4 Reducibility Index Values (RIV)

This is a measure of the ease with which oxygen can be removed from the sinter while charged into the blast furnace by the reducing gases (CO and H_2). It is a characteristic of reduction kinetics and a measure of the amount of fuel required to reduce a given weight of the sinter. This factor strongly controls the level of productivity of the blast furnace and ultimately the metallic yield, Fe.

The results obtained are given in Table 4.4 and Figure 4.4. It is clear from the results that the reducibility index value decreases as the blend ratio increases. This may be probably due to low porosity of the sinters produced because as the proportion of Agbaja iron concentrate increases the amount of fines in the sinter increases. Similar observation has been reported by Wegman, (1984) and Oloche et al., (2001) attributed the decrease in

reducibility with increase in the proportion of fine material in the sinter to be as a result of the reduction in the surface area of voids accessible to the reducing gases. The inability of sinter to reduce may also be due to the presence of some minerals such as fayalite, Ca-olivines, ferruginous glasses and brown millerite present whose melting temperatures are higher than the sintering temperature. However from the results, it can be seen that sinter blends with 10 – 15% Agbaja has values of reducibility index which can be compared favourably with the specified minimum of 70.00-79.00.

However, the blend with the ratio of 10% to 90% Agbaja to Itakpe has a maximum of value of reducibility index, hence, it is the most suitable because the higher the reducilbility index value the stronger the ability of the sinter to be reduced by the reductants (CO and H_2) in the blast furnace.

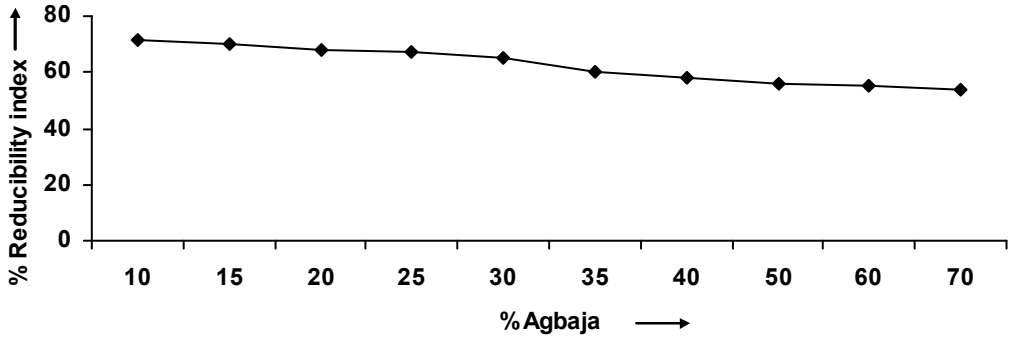


Fig 4.4: Variation ofReducibility Index with blend ratio

4.2.5 Reduction Decrepitation Index Values (RDIV)

Reduction Decepitation Index is a measure of the resistance of the sinter to some forces due to thermal shock from sudden exposure of the sinters to exhaust gas temperature at the stack of the furnace during smelting.

The results obtained are presented in Table 4.5 and Figure 4.5. It can be observed from these results that as the blend ratio increases, that is, as the proportion of Agbaja iron ore concentrate increase the reduction decrepitation index values decrease. This decrease in values may be attributed to the decreases in porosity because the Agbaja iron ore concentrate is finer. With sinter blends having 10 - 15% Agbaja iron ore concentrate meeting the specified minimum standard of 29.00 - 35.00 (Ispat,2004). It should be noted that the lower the values of the decrepitation index, the better the sinter and the easier its reduction at the stack without decrepitating. The 10% to 90% Agbaja to Itakpe satisfy the specification most.

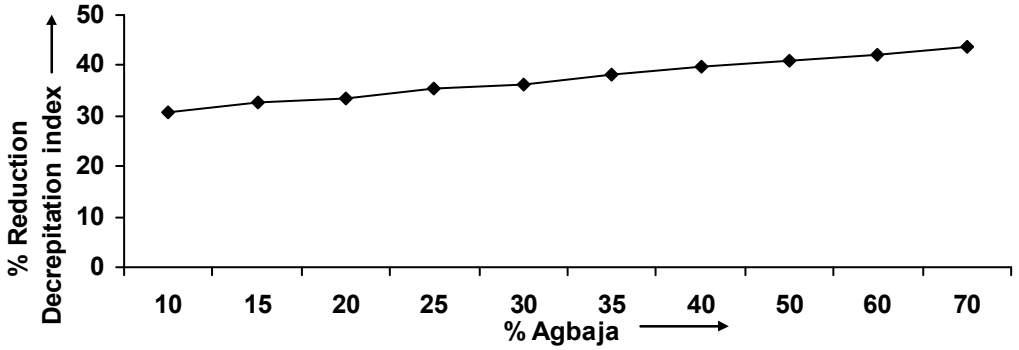


Fig 4.5: Variation of R.D.I with blend ratio

4.2.6 Chemical Analysis of Sinters

The comparative analysis of the chemical parameters of the blends and blast furnace specifications are given in Table 4.6. The major consideration in the selection of sinters for blast furnace operation are %Fe, % CaO, $\%Al_2O_3$, $\%SiO_2$, %P and the basicity (CaO/SiO_2). While it is desirable to have high iron content, basic gangue should be

moderate to limit the amount of fluxing agents.

From the results obtained, it can be seen that the iron content decreases from 65.45 to 61.32%, lime from 13.59 to 10.34%. However, Alumina increases from 1.98 to 4.12%, silica from 5.61 to 7.86%. Also the phosphorous increases progressively from 0.09 to 0.41% while the basicity decreases as the blend ratio of Agbaja iron concentrate increases. Considering the phosphorus content, only the first two blends whose [P] ≤)0.12% met the blast furnace specification for pig iron production as pointed out be Tupkary et al., (1998). However, increasing the percentage of Agbaja in the blend will result to high phosphorus pig iron, which may not be economical to steel makers.

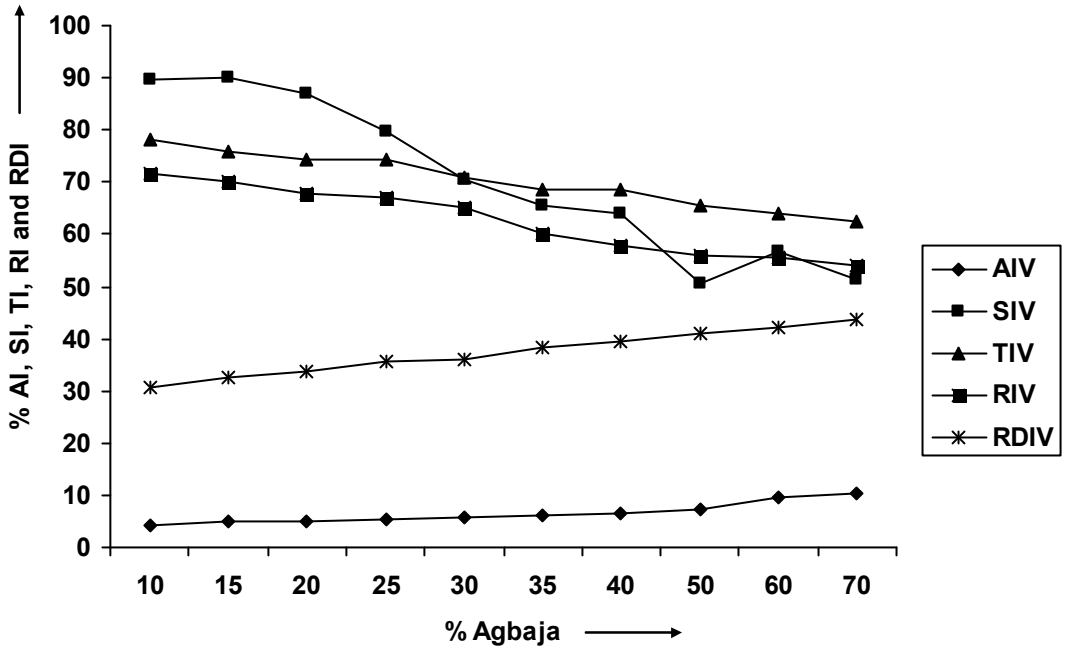


Fig 4.6: AI, SI, TI, RI and RDI against blend ratio

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the results of both the physical tests and chemical analysis carried out on the sinters produced, the following conclusions may be drawn:

1. Up to 10% of Agbaja concentrate could be blended with 90% of Itakpe concentrate to produce sinters that meet most of the specifications required of sinters for use in Pig iron production through the blast furnace route.
2. That the large deposit of Agbaja Iron ore can be utilized by blending with Itakpe iron ore thereby increasing the source of iron ore for the Nation's Iron and Steel industries and it can also increase the lifespan of the Itakpe iron ore deposit.
3. The pig iron produced could be refined to get the required steels using any method that can handle medium Phosphorus pig iron like Basic oxygen furnace route using any of the followings LD - AC, Kaldo etc.

5.2 RECOMMENDATIONS

Based on the outcome of this work, it is recommended that;

1. Further work be carried out on swelling index, hot compression strength and low temperature behaviour of the sinter blends.
2. That Phosphorous levels in the sinter blends be determined more accurately instrumental method using more sensitive machines like phosphorous analyser and spectrometer if available.

3. The possibility of using the same blends for the production of pellets should be explored in order to widen the areas of utilization of the Agbaja iron ore deposit.

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