EFFECT OF LOCALLY AVAILABLE BITUMEN ON THE COKING PROPERTIES OF LAFIA COAL.

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (M.Sc) IN METALLURGICAL AND MATERIAL ENGINEERING

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NOVEMBER, 2008

DECLARATION.

I, **DAVID Mathias,** declare that this thesis has been conducted by me under the guidance and supervision of my supervisor and has not been presented or accepted in any institution for the award of degree. All other sources of information are acknowledged by means of references.

…… ……

Signature Date.

CERTIFICATION.

This thesis entitled **Effects of locally available bitumen on the coking properties of Lafia coal** by **DAVID Matthias (**M.Sc/ENG/47984/05-06) meets the requirements for the award of Master of Science Degree in Metallurgical Engineering of the Ahmadu Bello University, Zaria and is approved for contribution to Knowledge and literary presentation.

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DEDICATION

This project is dedicated to Almighty God and my late Mother.

ACKNOWLEDGEMENT

This thesis could not have been completed without the guidance and direction from my supervisor, Prof. Oyihi B.Oloche, who aided from start to finish with advice on everything from test procedures to data analysis; your kindness shall always remain fresh in my mind, for giving my life a purpose.

My appreciation will not be complete if I do not appreciate my Head of Department Dr .O. Aponbiede. To my Lectures, thanks for influencing my life to the path of achieving this goals.

I would like to thank my colleagues and friends for their cooperation and continuous encouragement. Also I am very grateful to my friends, Amina Sidi and my dear friend Capt. J.O. Shuaibu for the support and care to me during the course of this programme.

Finally, I give thanks to my Father for his care and encouragement.

May god bless you all.

ABSTRACT.

To achieve high productivity, the blast furnace requires high quality coke. The coking properties of coke are directly related to the coke rate. The higher the coking properties, the lower the cost per tone of hot metal (pig iron) produced. Analysis of available data on Nigeria coals indicates that Lafia coal is slightly coking. In order to enhance its (Lafia coal) properties, effect of locally available bitumen (Ondo) was investigated. Proximate analysis, Free swelling index, Gray king, Dilatometry, Shatter and abradability tests were carried out on Lafia coal – Ondo bitumen blends. The blend ratio of 70 -30% Lafia coal – Ondo bitumen shows some significant improvement on the coking properties of Lafia coal. The Test confirms a reduction of high ash content of Lafia coal from 17.82% to 8.21%, free swelling index from ½ to 3 , Gray – king coke value from B to F for Lafia coal upon the addition of bitumen. From the research, a ratio of 70- 30% of Lafia coal and Ondo bitumen of 250µm sieve showed that the coking properties were significantly enhanced.

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CHAPTER ONE

1.0 INTRODUCTION

Many industrialized economies depend on iron and steel for modern technological and infrastructural development. To achieve high productivity the blast furnace requires high quality coke as a source of energy, reducing agent and a support material for furnace burden (Gibson, 1997)

In the blast furnace process of iron making the most expensive material used is coke, which is a brittle porous, grayish solid fuel obtained from the carbonization of coking coal (Gibson, 1997)

Despite the general decline in the coal industry world wide over the last twenty-five years, the demand for coking coal in the metallurgical industry has remained strong due to the predominance of the blast furnace process in meeting the increasing demand for steel (Damisa, 2001)

In Nigeria only the Lafia –obi coal has proven to be slightly coking, although it has high sulphur and ash content which tend to limit its use for the production of metallurgical coke. With this limitation it cannot be used directly except when blended to achieve good quality coke (Damisa, 2001).

At present, due to non availability of coking coal, the iron and steel company will have to spend billons of Naira to import coking coals, which are not yet discovered in the country. This scenario is difficult to sustain, therefore effort to develop processes or techniques to produce coke from non –

coking coal is imperative (Oyedeji, 1994). Efforts in this direction resulted in blending of coals and evaluation of engineering properties of bitumen. (Oyedeji, 1994 and Owolabi, 1997).

1.1 BACKGROUND OF STUDY

In the past five and a half decades, there have been researches on the characteristics of Nigerian coals. The study of the chemical and physical properties of Nigerian coals was made by Powell Duffrym technical service limited between 1947 and 1951. The obtained result was intangible and therefore further investigation was called for (Deseward and Casey, 1983).

In an analysis by the Steel Development Department through some foreign consultants on the ultimate and proximate analysis of Nigerian coals, a recommendation of blending ratio 3 and 4% to 97 and 96 % local – imported coal was made for Ajaokuta Steel Company. The recommendation was economically not suitable for a developing nation like Nigeria because of the huge cost of import duties (Uwadiale and Adahama, 1995).

At laboratory scale, National Metallurgical Development Center, Jos, took a giant step forward in producing a coking blend from Nigeria coals, employing the foreign Gully Eagles prime coking coal for maximum ash content of 10% specification for Metallurgical coke, only 13% local (Lafia) and 28% (Enugu) coal could go into the blend with the prime coking coal

(Eagle Gually). A ratio of this sort is not economically good considering the heavy charges placed on import duties (Uwadiale and Adahama, 1995).

In a research, Oyedeji (1994), Lafia coal was blended with Australian coal at different percentages of imported – local coal, a recommendation of 60 – 40% was made. Based on the result of the analysis, the ash content of the blend was too high and thus fall short of the specification of the blast furnace coke. Although the sulphur content was reduced to the recommended percentage of the blast furnace specification.

Analysis of the blend of imported Agro- allied coal and Lafia coal done by Tyoden, 1997 gave a recommendation of 70 – 30% imported – local coal, but real coking properties were not achieved.

The software developed for the optimization of Nigerian coal blends for making coke used in the blast furnace process by Damisa (2001), was an on-line one. The results of the input of the program in Fortran 77 environment shows that, 20 % of the blend of Nigerian coals could be blended with 70 % of foreign coals (prime coking coal). A ratio of this sort is not economically good considering the charges on importation.

All these deficiencies open ways for further researches on the possible way of upgrading the coking property of Lafia coal.

1.2 AIMS AND OBJECTIVE OF STUDY

1. To upgrade the physical and chemical characteristics of Lafia coal to meet the required standard for metallurgical coke production.
2. To investigate the effect of bitumen addition on the coking properties of Lafia coal.

1.3 JUSTIFICATION.

Previous investigations carried out on the Lafia coal showed that, the coal is slightly coking, although it has high sulphur and ash content which tend to limit its use for production of blast furnace coke (Oyedeji, 1994)

The study indicated that Lafia coal could be blended to improve its coking and caking ability. Hence, further investigation and analysis of the coking characteristics of Lafia coal is imperative for utilization in the blast furnace. The utilization of Lafia coal by Ajaokuta and other metallurgical based industries will promote development of industries through effective supply of products to priority sector such as mining, engineering, energy, chemical, construction, transportation, communication, agriculture and agro-allied industries. It will also diversify the source of income for the nation's economy, conserve scarce foreign earnings, create employment opportunities as well as encourage development of appropriate indigenous technology.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 COAL AND ITS FORMATION.

According to Chung and Geer (1997), coal consists of a complex mixture of organic chemical substance with small amount of nitrogen and sulphur. The organic materials are derived mainly from plant remains, which have undergone various degree of decomposition, physical and chemical alteration after burial in the peat and swamps (Damisa, 2001).

Coal is not one material but many; and it did not form all by it self but in the presence of a great many other geometrical, mechanical, thermal and chemical processes (Tastsch, 1980). According to Chung and Geer (1997), coal formation may have been influenced by bacteria, temperature, time and pressure.

2.2 RANK OF COAL.

The stage of carbonization reached by a coal determines its rank. Rank of a coal can therefore be defined as the degree of its alteration starting from decomposition of materials to formation of solid blocks. Determination of rank is based upon chemical composition and proximity value for mineral matter free coal (Tyoden, 1997).

2.3 TYPES OF COAL.

According to Chung and Geer (1997) coal is classified into six major types. [i] Peat [ii] Lignite [iii] Sub- bituminous [iv] Bituminous [v] Semi- anthracite and [vi] Anthracite.

2.3.1 PEAT

It is a brown fibrous mass of partially decayed material that has accumulated in- situ water- logged conditions. It is considered as the one with the lowest rank in the range of coals. It is a non- commercial fuel and has no metallurgical importance. In most cases, it is not considered as a variety of coal (Tyoden, 1997).

2.3.2 LIGNITE

It is more compact than peat. It is the first product of coal formation. Its carbon content is relatively high. Lignite has no metallurgical importance, but where available in large quantity, it is dried and used industrially just like peat for generating electricity, gas production and for domestic purposes. In some countries, it is used for steam raising and as a source of low temperature distillate (Blyth and Defreitus, 1975).

2.3.3 SUB- BITUMINOUS COAL.

Sub- bituminous coals are coking coals and contain between 81.2 – 90.3% carbon, 4.5 – 5.2 % hydrogen, 4.0 – 4.5% volatile matter. The coke obtained from these coals are hard and strong (Damisa, 2001).

2.3.4 BITUMINOUS COAL:

This is the most important and includes all coking coals. The coal contains 82.5 – 90.6% carbon, 4.5 – 5.0% hydrogen and 3.5 – 4.1% volatile matter. It possess good coking properties and thus is used for metallurgical purposes. (Tastsch, 1980).

2.3.5 SEMI ANTRACITES

This is a high rank coal. It is expensive, and used industrially for central heating. It is used in cases where the absence of smoke is important. It contains 88 – 90 % carbon, 2 – 4 % hydrogen and 3 -5 % volatile matter (Tastsch, 1980).

2.3.6 ANTHRACITES

This is the highest rank coal which is most matured. It is a scarce and expensive high – grade fuel used industrially for steam raising and central heating. It is characterized by bright luster and uniform texture. Anthracite is used to a large extent in the form of briquettes and for those purposes where the absence of smoke is important. It contains 90 – 93% carbon, 2.0 – 3.0% hydrogen and 2.0 – 4.0 % volatile matter (Krevelen, 1983).

2.4 CHARACTERISTICS AND SELECTION OF COKING COALS.

The primary essentials in the selection of coking coals are ultimate analysis and proximate analysis. They are also required at frequent interval in order to ensure maintenance of quality, once the coal has been selected.

In ASTM classification, the rank of most coking coals are defined by their proximate analysis and the heating values determination. Analysis including moisture, ash, sulphur and sometimes phosphorus also shows the grade of coal (Damisa, 2001). By correlation information on the rank and the proximate analysis of similar coal in a coke oven, it is often possible to make preliminary estimate of the yields and qualities of the coking product to be obtained from the former (Damisa, 2001)

A good cooking coal or blend must posses the correct combination of swelling, coking and plastic properties so that during heating they would cause the coal particle to fuse together to form a strong coherent mass which fractures along planes of weakness to have a preponderance of pieces 20mm size range on cooling (Leonard, 1979).

Other characteristics, which affect the coking behavior of coals, are agglutinating value and bulk density (Damisa, 2001)

2.5 COAL RESOURCES IN NIGERIA.

There are five economically important seam of sub-bituminous coal so far recognized in Nigeria and are located in the south- east and middle belt of the country.

Nigeria has over 2.5 billion tones of coal with proved reserves of about 639 million tones out of which about 25million tones have been mined (Damisa, 2001). Analysis of some Nigerian coal deposits is shown in Table 2.1.

Table 2.1: ANALYSIS OF NIGERIAN COAL DEPOSIT.

Coal Deposit	Proven Reserve (Million tones).	% Moisture	% Volatile Matter	% Ash	Fixed Carbon (%)	% Sulphur	% Phosphorus
Enugu	254	6.65	44.56	11.19	53.35	0.75	0.0012
Okaba	323	9.56	42.33	10.12	50.05	0.72	0.0013
Owukpa	132	4.06	40.16	10.35	50.65	0.55	0.0012
Lafia	222	8.99	32.61	17.82	52.65	4.02	0.0081

Source: Nigerian Coal Corporation (1999).

Investigation and test carried out on Nigeria coal revealed some distinct characteristics. Some of the coals examined are Enugu, Okaba, Owukpa, and Obi coal (Oyedeji, 1994).

2.5.1 ENUGU COAL.

The coal deposit is predominantly sub –bituminous, of medium quality and non-coking. It is friable and susceptible to weathering. The Coal cannot produce metallurgical coke of high quality on its own.

Investigation revealed that only 5% of Enugu coal could be used when blended with imported metallurgical coal. (Oyedeji, 1994). It has high moisture and volatile matter contents and very high characteristics for low rank coal with high resinous and waxy materials, but contains low sulphur. It is also non- agglomerating in character.

2.5.2 OKABA COAL.

The coal deposit belongs to the sub – bituminous type of medium quality and non – coking. It is non-coking coal with low sulphur and ash contents. It reacts to weathering, not easy to grind, non-caking, rich in resinous and waxy materials and gives high yield of tar and oil gas of high calorific value. It is self – binding under pressure (Oyedeji, 1994).

2.5.3 OWUKPA COAL.

The deposit possesses virtually the same characteristics with Okaba coal, except that it has less moisture content (Oyedeji, 1994).

2.5 .4 LAFIA- OBI COAL.

Of all the coal deposits in the country, Lafia –obi coal has proven to

be the best because of its coking and caking abilities. Its sulphur and ash contents are high, hence limits its use for production of blast furnace coke of acceptable quality. The coal deposit is bituminous in nature, it has the lowest moisture about 1.4%, medium volatile contents of about 29.4% and less susceptible to weathering (oxidation process). When heated, it passes through plastic stage and cake or stick together into a mass and as a result does not combust fully and clogs the production system (Chathley and Akinlolu,1983).

2.6 REFLECTANCE OF COAL.

This is an important property that can be studied under the microscope. ‘The reflectance of vitrinite’. The reflectance of vitrinite increases with the rank of the coal. (Damisa, 2001). This property can be measured by mounting a photo multiplier on a microscope so that it receives light reflected from a very small area on the polished surface (about 2 microns in Diameter) and comparing the intensity with that reflected from the same area on a standard surface of known reflectance. This property is the only measurable parameter of rank, which is not influenced by changes in the proportions of the maceral groups; it can be used to predict the characteristics of coke made from a coal and the yields of products (Damisa, 2001).

2.7 HIGH TEMPERATURE CABONIZATION.

The equipment used for making foundry (for melting metal) or blast furnace (for smelting iron ore) coke is known as coke oven. It consists of a battery of 10 or 100 slot ovens side by side indirectly heated through the oven walls by hot gases produced from burning the gases evolved during carbonization (Pitt and Millward, 1979). Each oven may be charged with about 20 tones of coal and may be about 14m between doors, up to 6.5m high, average width 0.4-0.6m with a taping of 50-100mm to facilitate discharge of the coke –typical dimensions in modern designs (Pitt and Millward, 1979). Removable doors at each end seal the oven to prevent ingress of air and leakage of gas during the coking period.

The refractory lining of oven walls, flues and regenerator walls are made from silica brick, since they encounter the highest temperatures and the most severe mechanical stresses. The checker bricks in the regenerator are of fireclay. The battery is enclosed within a layer of insulating brick. The coal to be carbonized is stored in overhead charging bunkers located at each end of the battery and a predetermined weight is fed into a charging car which travels over the length of the battery to fill the individual ovens through charge holes in the over top. The sequence of charging, leveling and replacing lids is completed as quickly as possible within a few minutes. Coking is completed in about 12 to 80 hours depending upon width, flue temperatures used and the

type of coke required. The coke is then pushed from the oven by a ram into a quenching car. A program of charging, carbonizing and discharging of ovens within a battery is arranged so that during its life the whole battery is maintained at a fairly, even temperature and coke making is as near continuous as possible. The mass retained on a 38.1mm sieve is then a measure of the resistance to breakage and the mass passing 12.7mm sieve indicates the abradability (Leonard, 1979).

2.7.1 COKE PRODUCTION.

The coke making process involves carbonization of coal to high temperature (1100˚C) in an oxygen deficient atmosphere in order to concentrate the carbon. The commercial coke making process can be broken down into two categories (a) By –product coke making and (b) Non recovery / Heat recovery coke making. A brief description of each coking process is presented below.

(a) By - product coke production:

The coke making operation is comprised of the following steps. Before carbonization, the selected coals from specific mines are blended, pulverized, and oiled for proper bulk density control. The blended coal is charged into a number of slots type ovens wherein each oven shares a common heating flue with the adjacent oven. Coal is carbonized in a reducing atmosphere and the off- gas is collected and sent to the by product plant where various by products

are recovered. Hence, this process is called by product coke making. (Larry, 2001).

(b) Non- recovery / heat recovery coke production.

In Non – recovery coke, originally referred to as beehive ovens, the coal is carbonized in large oven chambers. The carbonization process takes place from the top by radiant heat transfer and from the bottom by conduction of heat through the sole floor. Primary air for combustion is introduced into the oven. Partially combusted gases exit the top chamber through “down comer” passages in the oven wall and enter the sole flue, thereby heating the sole of the oven. Since the by –products are not recovered, the process is called non- recovery coke making. In one case, the waste gas exits into a waste heat recovery boiler which converts the excess heat into steams for power generation, the process is called heat recovery coke making (Larry, 1994)

2.8 CHARACTERISTICS AFFECTING COKING COAL.

The characteristics of coals that affect their coking behavior are volatile matter, plasticity, swelling, agglutinating value and bulk density. (Afonja, 1989.)

2.81 VOLATILE MATTER

The concentration of volatile matter in the coal should be as low as is compatible with good coking properties. The yield of coke increases roughly as the volatile matter content of the coal decreases. The volatile matter content of the coal used for metallurgical coke usually ranges between 23 and 32

percent by weight. (Afonja, 1989). It also forms a very important basis for coal classification. Most classifications are based on volatile matter contents within the range 28 – 33 %. The gross calorific value is used in conjunction with volatile matter for classification.

2.8.2 PLASTICITY AND SWELLING CHARACTERISTICS.

When a coking coal is heated in the absence of air, a temperature is eventually reached at which the coal begins to soften. With most coking coals, this temperature is in the neighborhood of 400 ˚C (Leonard, 1979). As the temperature continues to rise, the coal fuses to a plastic mass, and gas and condensable vapors are evolved. With continued heating and evolution of gas the fused coal gradually resolidifies to the typical, cellular, coke structure. Final disappearance of plasticity from the mass usually occurs in the neighborhood of 500 ˚C. While in the plastic state, the coal may expand in volume, undergo no change or contract. When the coal expands most of the swelling occurs in a direction perpendicular to the heating surface. In a retort or coke oven, swelling coal exerts pressure on the wall of the oven.

Several authors (Leonard1979, Gibson1979, Krevelen, 1983 and Larry1992) agree that different coals show marked differences in their swelling and plastic characteristics. Non –caking coals, for instance, when heated, show the properties to only a slight extent, or not at all (Leonard, I979).

2.8.3 SWELLING DURING COKING.

A coal is termed ‘swelling’ when, on heating, tends to occupy a volume greater than that of its original mass. Since a volume change is almost impossible in a fixed wall coke oven, an expanding coal may be defined as one which develops a pressure against the walls of the oven.

The pressures developed against the brick walls of a coke oven by a swelling coal are often great enough to damage them severely.

Before an expanding coal is charged into a coke oven, it should be blended with a contracting coal to produce a mixture or a blend, which will be neutral. The simplest indication of the swelling of a coal is probably the coke button. It is evaluated by comparison with standard profiles
(BS1016, Part 12 1971)

2.8.4 AGGLUTINATING VALUE. .

The agglutinating (property of a coal that makes its particles to fuse or cake) value of a coal is useful in showing whether a coal will cake or not. It is essentially the binding quality of a coal at a temperature in the plastic range. The reduction in the agglutinating value of a coal is one of the best measures for its loss in caking power as a result of oxidation and it has been used to detect the deterioration in the coking properties of a coal during storage (Thomas, 1979). Agglutinating value test is useful in showing whether a coal

will cake or not. Thus, it helps in the selection of coals for carbonization, but it must be correlated with other significant characteristics of the coals before greater weight can be attached to it.

2.8.5 MINERAL MATTER IN COAL.

Mineral matter in coals remains in the coke produced from such coals In the coke oven, it occupies valuable space and heat is consumed in raising its temperature. The ash that is left when coal is burnt differs from the original ash present in the coal both in quantity and composition.

The original ash in coal before combustion is generally termed mineral matter. Some analytical methods are available for direct determination of mineral matter in coal (BS 1016 part 13 1971). But in the absence of the determined value, the mineral matter in a sample of coal can be estimated to a very close approximation from other analytical results by the formula given below. This formula relate the mineral matter to the ash and takes account of the chemical changes which take place in the mineral matter when the coal is burnt during the determination of ash.

$MM_{ad} = 1.13_{ad} + 0.8CO_{2ad} + 0.5S^{p}_{ad} - 2.8S^{a}_{ad} + 0.5Cl_{ad}$ (BS 1016 part 16 1971).

Where:

MM = mineral matter content

A = ash content

CO_2 = carbon dioxide content

S^p = Pyritic Sulphur content.

S = Sulphate sulphur content.

S = SO_3 content of the ash derived from the formula.

$S^{a}_{ad} = 0.4SO_3A_{ad}/100$

Cl = Chlorine content.

ad = Air dry

2.9 COKING TESTS

The behavior of coal on heating and whether the solid product is pulverulent or massive is of special importance and many methods have been suggested for its definition and measurement. These tests are:

2.9.1 GRAY- KING METHOD:

Coal (20g passing a 72 B.S sieve) is carbonized under standard conditions to 600˚C. If the carbonized residue is pulverulent with no sign of coherence, the term ‘non -caking’ is assigned. Coal which gives a hard, compact, non- fissured coke of the same volume as the original coal is termed G, while the intermediate letter designate coals whose coke friability decreases within this range. Coals of higher caking power are blended with 72 – mesh carbon to give a coke corresponding to type G and termed G_1 to G_{10} respectively, the subscript numbers indicates the number of grains of coke necessary in the 20 g blend (Damisa, 2001). Figure 2.1 shows types of coke from gray king assay.



A	Pulverulent
B	Just coherent, breaks into powder on handling
C	Coherent but friable on rubbing
D	Shrunken, moderately hard
E	Shrunken and fissured: hard
F	Slightly shrunken, hard
G	Hard, no shrinking (same volume as original coal) (= “standard” coke)
G^1	Slightly swollen, hard
G^2	Moderately swollen, hard
G^3	Highly swollen: fills the whole tube without increase in length
G^9	Very strong swelling; increased length

Figure 2.1: Types of coke from Gray-king assay.

2.9.2 GIESELER PLASTOMETER.

To form coke, coal passes from solid form through a fluid or plastic state to become a fussed porous solid. The temperature range of the fluid phase and the viscosity of the fluid are important features when blending coals for coke manufacturing. This parameter is measured by the Gieseler

Plastometer, in which a coal sample is pressed around a spindle under torque, as the coal reaches its fluid state, the spindle begins to revolve and the rate at which it turns is measured in dial division per minute (ddm) which is then plotted against temperature. Coals with high and low fluidity may be blended to obtain improved coking properties.

AUDIBERT – ARNU DILATOMETER.

Coal shrinks during carbonization and such volume changes that accompany the heating of coking coals are measured with dilatometer. Several methods have been develop for this purpose and the most widely used are the Audibert- Arnu and Ruhr dilatometer.

Dimensional changes in coal can be measured as a function of time .while the temperature of coals is measured at a constant rate. Curves record the length of a coal sample to define the extent of contraction and dilatation, and the temperature at which these changes begin or end .The properties are significant in determining the volume of coal that can be fed into a coke oven, and also in blending different coals for coke production. The resultant coke itself is subjected to rigorous test to confirm its strength and quality for use in commercial operation. (Larry, 1994).

CAKING TEST.

2.10.1 FREE SWELLING INDEX.

Free swelling index in BSI Nomenclature, the crucible swelling number (CSN) in ISO Nomenclature is a measure of the increase in the volume of the coal when heated, without the restriction of the exclusion of air. The test is useful in evaluating coal samples for coking and combustion.

The correlation between Swelling index and Gray –king value is shown below.

Gray king.	A	B	C	D	E	F	G	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8 G_9 .
Swelling index	1		1 ½	2	3		4	5		6		7		8	9

2.10.2 ROGA INDEX.

Roga index test is used to indicate the caking properties of coal. A sample coal is combined with a standard measure of anthracite and heated. The resultant button is then tested for mechanical strength, rather than the changes in dimensions.

2.11 BITUMEN.

Bitumen is a generic term defined by American Society for Testing and Materials (ASTM) as a class of black or dark colured solid, semi solid or viscous substances, natural or manufactured, composed principally of high molecular weight hydrocarbon of which asphaltic tars, pitches and asphatenes are typical. The British standard defines bitumen as a ductile viscous liquid or solid material, black or brown in colour having adhesive properties, consisting essentially of hydrocarbons derived from petroleum or occurring in natural asphalts and soluble in carbon disulphides or carbon tetrachloride (BS892, 1967)

According to Anil and Ronald (2000), bitumen is a complex mixture of molecules of predominantly hydrocarbon in nature. The chemical composition of bitumen according to Anil and Ronald (2000) can be further subdivided into:

(i) asphaltenes (ii) resins (iii) aromatic (iv) saturates.

These groups are called “SARA” Fractions (Anil and Ronald, 2000). The properties of bitumen are dependent on the properties of these four components and can vary depending on the deposit.

Asphaltenes are a product of resin development by geological or processing effects. They are the thickening agent of bitumen. Resins are chemically very similar to the asphaltenes. They consist of mainly polycyclic

molecules containing saturated aromatic atoms. The aromatic contributes to the ductility of bitumen. The fluidity of bitumen is imparted by the saturates and the aromatic fraction, which in combination with the asphaltenes produce complex flow behaviour (Branthauver et al 1992). The chemical composition of bitumen may be controlled by crude source, manufacturing processes or by additive systems. This has the effect of improving performance to a desired optimum based on field or performance design. (Holleran, 1990)

According to Branthauver and Holleran (1992) bitumen contains 83.0-87.0% carbon, 10.0-14.0% hydrogen, 0.1-2.0% nitrogen, 0.05-1.5% oxygen 0.05- 6.0% sulphur and (Ni and V) metal >1000ppm

A notable deposit of natural bitumen in Nigeria which has been reported as the second largest in the world is located spanning from Ijebu – Ode of Ogun state, to Okitipupa of Ondo state to the western margin of Edo/ Delta states. The bitumen-bearing zone is about 120km long and 6km wide, and the thickness ranges from 0.5m to over 40m with an average of about 6m (Adegoke et al, 1980).

A lot of efforts had been made to carry out research work on the Nigerian bitumen of which greater attention was focused on the tar sand deposits of western Nigeria by some groups, organizations and individuals (Owolabi, 1997). The earlier research included Cousey D.G and Hubbard (1963) in conjunction with Hitch L.S of road research laboratory England. Cousey et al (1963) collected four samples of bitumen and investigated its

composition and physical properties. Results obtained showed that the material (bitumen) may be suitable for use as a binder

Recent work which are considered to be the most intensive were carried out by the geological consultancy unit of Obafemi Awolowo University Ile-Ife and led by Professor Adegoke (Adegoke etal, 1980 and Adedimila, 1987). The work of the Adegoke led group was manly exploratory and geological in nature while that of Adedimola involved engineering investigation. In Adedimila (1987) investigations were carried out in order to analysis the chemical composition and the engineering properties. It was found that, Ondo bitumen contain 85.50% of carbon, 13.14% hydrogen, 0.50% nitrogen, 0.80% oxygen and 0.0 6 % sulphur, and that it can be used as a pavement material.

CHAPTER THREE.

3.0 MATERIALS AND METHOD

3.1 MATERIALS:

To achieve the aim of this work, various steps were taken, which included collection of coal samples from Lafia – Obi coal. Where some works has been done by the National Steel Raw Materials Exploration Agency.

Bitumen was collected from Lamudifa village north of Agbabu in Odigbo local government of Ondo state. Experimental work such as chemical analysis of the coke produced from the blend of coal and bitumen were carried out at the National Metallurgical Development Centre, Jos,

The National Steel Raw Material Exploration Agency Kaduna, The Kaduna polytechnic and Datum Technical Service Calabar. The step taken to achieve these objectives involved sample collections, analysis of sample, determination of physical characteristics of the blend produced from the coal sample and the plain bitumen using weight percent. .

3.2 EQUIPMENT.

The following equipment were used in this research work.

A metallic mortar and piston, heating furnaces, retort glass tube, meddler weighing balance, cotton wool, stop watch, silica crucibles with lid having a ring handle, spatula, Bunsen burner, standard profile rack, electronic

sensitive weighing balance, dessicator, galvanometer, gauge, ram, press, dilatometer tube and pistons, electric furnace and steel plate (3.8mm).

3.3 SAMPLE COLLECTION.

The coal samples used for this work were obtained from the underground mines and out crops of Lafia -Obi coal. From the underground mines, coal cutting saw was used to obtain the sample by cutting out a full column about 10cm square between root and floor as suggested by Thomas (1979). A hard auger was employed to obtain the sample from the out crop as it was impossible to obtain samples beneath the surface as the shafts sank in the 1970's are now flooded and filled up. However, preserved samples of seam 12 of the coal which were carefully bagged in samples bags were obtained from laboratories of the Department of Mineral Resources Engineering, Kaduna Polytechnic and National Steel Raw Material Exploration Agency, Kaduna. The sample of Ondo bitumen was collected with improvised open drive sampler.

3.4 SAMPLING METHOD.

The chute sampling technique was used while the sample of bitumen was collected with improvised open drive samplers.

The run of mine sample of Lafia coal was poured gradually into the sampler hopper along its length. The sample splits into two portions A and B. Portion A was splited into two sub samples C and D using the chute riffler.

Similarly Portion B was splited into two sub – sample E and F C and E were combined and passed through the sampler to obtain two portion G and H.
G and H were splited into two samples to obtain B1, B2 and B3, B4.

D and F were combined and passed through the sampler to obtain two-portions, .J and K to obtain B5, B6, and B7, B8. Any of the samples (B1 - B8) can be taken; in this case, B1 was weighed and was placed and screened in the 20 mesh (850 μm) screen. .

3.5 COAL CLEANING.

The coal samples were washed thoroughly using heavy media separation (Ferro silicon) to remove all dirts and debris of sand that might be attached with the coal from the mines

3.6 BLENDING.

Blending of the coal samples (coal and bitumen) was done using the various weights of the sample at the ratios required in grams. The various grams, which were calculated in percentages, were strictly adhered to. The mixing was properly done using spatula to avoid samples concentrating in one place. The weights are 90-10%, 85-15%, 80% – 20%, 75% –25%, 70% –30%, 65% -35%, 60%- 40%, 55%- 45%, 50% -50% of coal and bitumen. The various tests to prove the coking properties were carried out on each of the blends.

3.7 DETERMINATION OF MOISTURE CONTENT.

About 10g of the finely ground blend was weighed and placed in the silica dish. The uncovered dish and the blend were placed in the oven at 110ºC and heated to constant weight.

After about an hour, the silica dish was removed and allowed to cool in a dessicator. The dish and sample were replaced in the oven for a further fifteen minutes, after which the dish was cooled and reweighed. When there was no further loss of weight, the difference (loss) was expressed as percentage moisture content of the sample.

% Weight of Moisture $M_3 = M_2/M_1 \text{ X } 100$……. 3.1

Where M_2 = weight of the blend after heating

M_1 = weight of the blend before heating.

3.8 DETERMINATION OF VOLATILE MATTER CONTENT.

Two crucibles to be used were heated to a temperature of 900˚C in the furnace to obtain their constant weights. They were allowed to cool in air and then in the dessicator. Weights of the crucibles were taken in a weighing balance. 1 gram of the sample was taken into the crucible to avoid partial combustion of the coke. residue.

Temperature of the furnace was maintained at 900˚C with the sample inside the crucible kept inside it. Two drops of benzene were added to the

sample which was allowed in the furnace for about seven minutes. The aim of benzene addition was to hasten volatile matters reaction.

The crucibles were removed after the given period and allowed to cool in air. Reweighing of the samples was done and their differences used to calculate the percentage of volatile matter in the coal sample.

% volatile matter = W_b / W_a X 100. …… 3.2

% Volatile matter on Dry air base = W_c X100 / 100 - M_3 … 3.3

Where

Wa = weight of the blend before heating.

Wb = weight of blend after heating.

Wc = percentage weight of volatile matter.

M_3 = percentage weight of moisture content.

3.9 DETERMINATION OF ASH CONTENT.

Two flat bottom crucibles were kept inside a furnace and heated to a temperature of 825˚C. After attaining this temperature; they were removed and allowed to cool in air before being placed in a dessicator for further cooling.

One gram of the sample was put into the furnace that was maintained at 825 ˚C. It was allowed there for 75 minutes.

Crucibles were removed and cooled in air for ten minutes before taken into dessicator for further cooling. Weight of the ash was determined by re-weighing the crucible and subtracting it from the initial weight of the crucibles

containing the samples. Percentage ash was determined as in equation 3.4 and 3.5.

% ash a_2 / a_1 X 100 …… 3.4

$$\% \text{ D.A.B.} = \frac{\% \text{ ash as analyzed}}{(100 - \% \text{ moisture})} \times 100 \quad \ldots\ldots\ldots\ldots 3.5$$

Where,

a_1 = Average weight of sample.

a_2 = Average weight of ash.

a_3= Average %weight of ash on D.A.B.

3.10 DETERMINATION OF FIXED CARBON CONTENT.

Fixed carbon F.C = 100 – (%moisture +% volatile matter on D.A.B + % ash D.A.B).

3.11 DETERMINATION OF FREE SWELLING INDEX.

The purpose of the test is to access the swelling properties of the coals when heated in a covered crucible under standard conditions to a final temperature of 820 ºC. The coke button obtained by heating the finely ground coal to 820ºC was classified by comparing it with the outlines of a set of

standard profiles. The number of the profile most closely corresponding to the coke button obtained is the crucible swelling number.

The air –dried blend to be tested was ground to pass a 0.2mm sieve. 1g of the freshly grounded coal was weighed into a crucible. The crucible was covered with its lid and placed upright on the silica triangle supported in the draught shield. The gas was lit and heated for thirty minutes for the flame of the burning volatiles matter to die out. The gas was then turned off and the crucible allowed to cool. The coke button was carefully removed and compared with the standard numbered profiles.

3.12 DILATOMETRY TEST OF THE BLEND.

A pencil made of powdered blend of bitumen and coal was inserted in a well – calibrated narrow tube and topped by a steel rod (piston), which slides in the bore of the tube. The whole was heated to 820ºC.

Regular reading of the displacement of the piston as a function of the temperature was noted, and the displacement observed was expressed as percentages of the original length of the pencil.

If after contraction has taken place, the piston does not return to its original level, the dilatation is calculated from the difference between the final level of the piston and the original zero level, but reported as negative.

3.12.1 PREPARATION OF THE COAL /BLEND PENCIL.

The mould was placed on its support with the larger orifice upward and funnel set on the mould. The coal was placed in the funnel and lightly tempered into the mould without moving the funnel. The pencil was then removed from the mould. The length of the pencil was adjusted to 60+ 0.25mm by cutting away as much as necessary of the thick end with a fine blade.

3.12.2 DETERMINATION OF DILATION.

The blend was heated at 3ºC/min. The blend pencil was carefully inserted, thick end first, in the dilatometer tube and pushed very gently into position with the piston.

The tube and content were placed in the furnace when the temperature was 330 ºC. After the charge dilatometer tube had been inserted in the furnace, the indicator pointer was allowed to reach equilibrium before adjusting the zero on the scale. Immediately the temperature began to drop, heating was regulated so as to regain the temperature of 330ºC at the end of 10 min. After 340ºC had been reached, the rise in temperature was essentially very steady, minutes by minutes and equal to the rate chosen with a tolerance of 0.5ºC per min. During each 5 – min period the heating rate was adjusted to correct any deviation observed in the preceding period in order to avoid the accumulation of errors.

Heating was stopped and the piston was immediately removed in order to prevent its getting jammed. The dilatometry test for the coal sample was also done using the same procedure.

3.13 DETERMINATION OF GRAY –KING COKE TYPE.

To asses the coking properties of the blend of coal by carbonizing in a laboratory assay under standard conditions and reaching a final temperature of 600 ºC. The coke residue from the carbonization of finely mixed blend at 600ºC was classified by comparison with a series of prescribed coke types.

10grams of the blend was air dried and ground to pass a 0.2 mm sieve. The blend was weighed on a meddler weighing balance and transferred with spatula to the main body of the retorts, which was held almost vertically .The retort was turned into a horizontal position with the side – arm downward and distance rod inserted so that the face of the piston was 15cm from the closed end of the retort. The coal was then spread over this length 15cm as an even layer. The open end of the retort and the positioned distanced rod were held in one hand and the closed end of the retort in the other. By careful shaking, the coal was made to spread into an even layer and was then lightly consolidated by tapping the retort on the bench. Coals which have crept past the distance rod were carefully pushed back on the main body of the coal by strokes of the distance rod, and the coal re- leveled and again consolidated.

The distance rod was then withdrawn and replaced by a small pad of asbestos disk notched to allow free passage of gas. The assembly was then clamped into position on the frame carrying the furnace. The furnace previously raised to a steady temperature of 325ºC, rested on the frame behind the retort and was screened from it by a piece of asbestos board. The asbestos board was then removed and the furnace drawn smoothly and quickly over the retort, into the normal working position. Timing was started from this instant and the heating current increased by a pre- determined amount to give as nearly as possible, a regular rise in temperature of 5 ºC/min.

When the retort was withdrawn from the furnace the temperature initially dropped to about 300ºC and then started to rise at approximately the required rate of 5ºC /min. When the temperature reached about 590 ºC, the current was reduced to that required to maintain the furnace at 600ºC.

The retort was retracted from the furnace, which cooled very rapidly. When it was cool enough to handle, the tar receiver and bung were removed and the traces of tar fouling the mouth and side –arm of the retort were burned off or removed by solvents. The carbonized residue was then slid out of the retort for examination.

3.14 DETERMINATION OF STRENGTH OF COKE BY SHATTER TESTS

Coke larger than 50.8mm was dropped from a height of 1.83m to a steel plate four times in succession and the broken coke was then screened. The

shattered coke is screened through 3.8mm screen. The weight of fractured coke retained on the 3.8mm screen sieve is the shatter index. This then is a measure of its resistance to brakeage and that passing 12.7mm indicate abradability.

3.15 DETERMINATION OF SULPHUR IN THE BITUMEN SAMPLE.

Eschka method for the determination of sulphur was used.

1 g of air dried sample of bitumen was mixed with 3 – 4 g of Eschka mixture (2 part calcined MgO and 1 part anhydrous Na_2CO_3) the mixture was placed in a platinum crucible and was covered with about 2 g more of Eschka's mixture. The mixture was heated very gradually to drive off the volatile matter with frequent stirring of charge by a platinum wire to allow free access of air. The heat was increased after about 30 minutes to a dull redness and the charge was heated until all the coal was oxidized (indicated by change of gray color to yellow or light brown). After the oxidation was completed, the crucible was removed and cooled.

The MgO from the Eschka mixture prevents the fusion of Na_2CO_3 and also keeps the mixture porous (open) to allow the access of air. Fusion of Na_2CO_3 retarded the oxidation process. Oxides of sulphur from the combustion of coal and any pyrites reacted with the alkaline Eschka mixture to form sulphate and sulphites. The fussed mass was digested with 100ml of hot water

for 30 minutes and the clear liquor was decanted through filler into a beaker. The residue was washed 2-3 times with hot water. The total filtrate was made to about 150ml. about 5ml of bromine and a little Hcl were added and the solution was boiled to convert any sulfite present to sulphates. The sulphates in the filtrate were then precipitated as $BaSO_4$ by adding 10 % solution of $BaCl_2$ (10ml) to the hot solution and then filtered and washed with hot water 5-6 times. The barium sulphate was then ignited and weighed. A blank test was conducted with the same amount of Eschkla mixture and other reagents as used in the actual experiment and under exactly the same conditions. Percentage of sulphur was then calculated as follows:

Sulphur (%) = (A – B) X 13.735/C.

Where, A= weight of Baso4 precipitated from sample in g.

B= weight of BaSO4 precipitated from blank in g

C= weight of sample of bitumen in g.

3.16 DETERMINATION OF CARBON AND HYDROGEN IN THE BITUMEN

About 0.2g of finely ground air – dried bitumen was burnt in a stream of oxygen in a silica tube at 800 ˚C. The resulting water and carbon dioxide were absorbed in $CaCl_2$ (B.S. 1016 Pt, 1977).

$$\text{HYDROGEN \%} = \frac{\text{Weight of } H_2O \times 1119 \times 100}{\text{Weight of bitumen sample}}$$

$$\text{CARBON \%} = \frac{\text{Weight of } CO_2 \times 0.2729 \times 100}{\text{Weight of bitumen sample.}}$$

3.17 DETERMINATION OF NITROGEN. IN THE BITUMEN SAMPLE

The percentage nitrogen was calculated by subtracting % Carbon, % hydrogen and % Sulphur from 100%

% Nitrogen = 100 – (% carbon = % hydrogen + % sulphur)

Note: The % nitrogen will contain some elemental loss on ignition. (L.O.I)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION.

Results of the chemical and physical tests carried out on Lafia coal and the blend of Lafia coal and Ondo Bitumen are presented below in Tables 4.1 to 4.7 and in Figures 4.1 – 4.7

The Lafia coal samples were analyzed first before blending at various ratios with Ondo bitumen to obtain their characteristics.

In the figures and tables the following abbreviations are used, and their meanings are as follows

L.F - Lafia coal
O.B - Ondo bitumen.
D.A. B - Dry air Base.
G- k - Gray –king coke type.
F.S.I - Free Swelling Index.

TABLE 4.1 CHEMICAL COMPOSITION OF ONDO BITUMEN.

Constituents	C	H	N	O	S	ASH	VOLATILE MATTER	MOISTURE
% Composition	70.59	4.44	0.67	1.78	1.11	4.45	14. 52	1.20

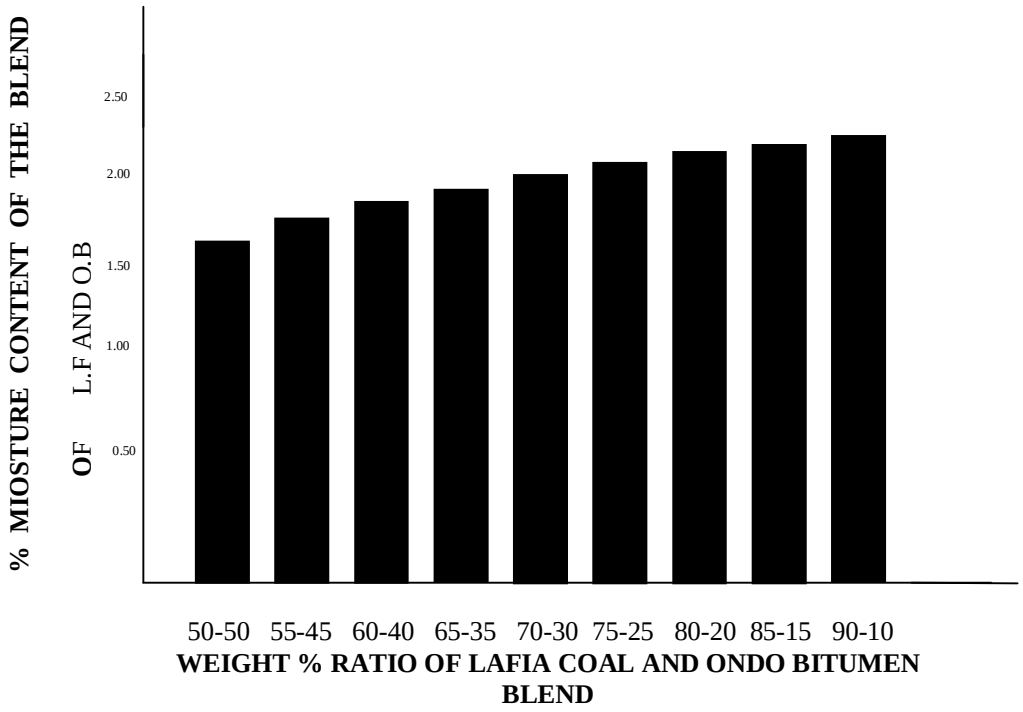


FIGURE4.1: Influence of bitumen on the moisture content of Lafia Coal.

Moisture content of Lafia Coal is 8.96%.

BLAST FURNACE SPECIFICATION: The Moisture content of coal used for blast furnace should be below 5% (Chung and Geer, 1975)

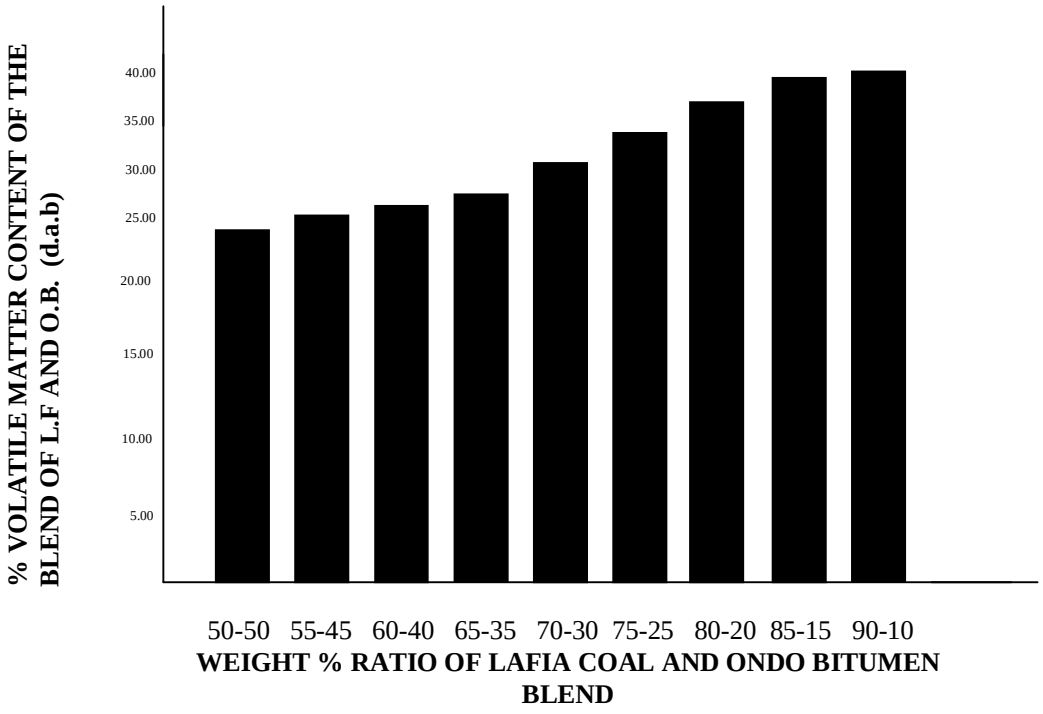


FIGURE4. 2: Influence of bitumen on the volatile matter of Lafia Coal.

Volatile matter content of Lafia coal = 30.32 % (D.A.B)

BLAST FURNACE SPECIFICATION: The volatile matter content of coal used for blast furnace usually ranges between 23 –32 % [D.A.B] (Wilson and Wells, 1975)

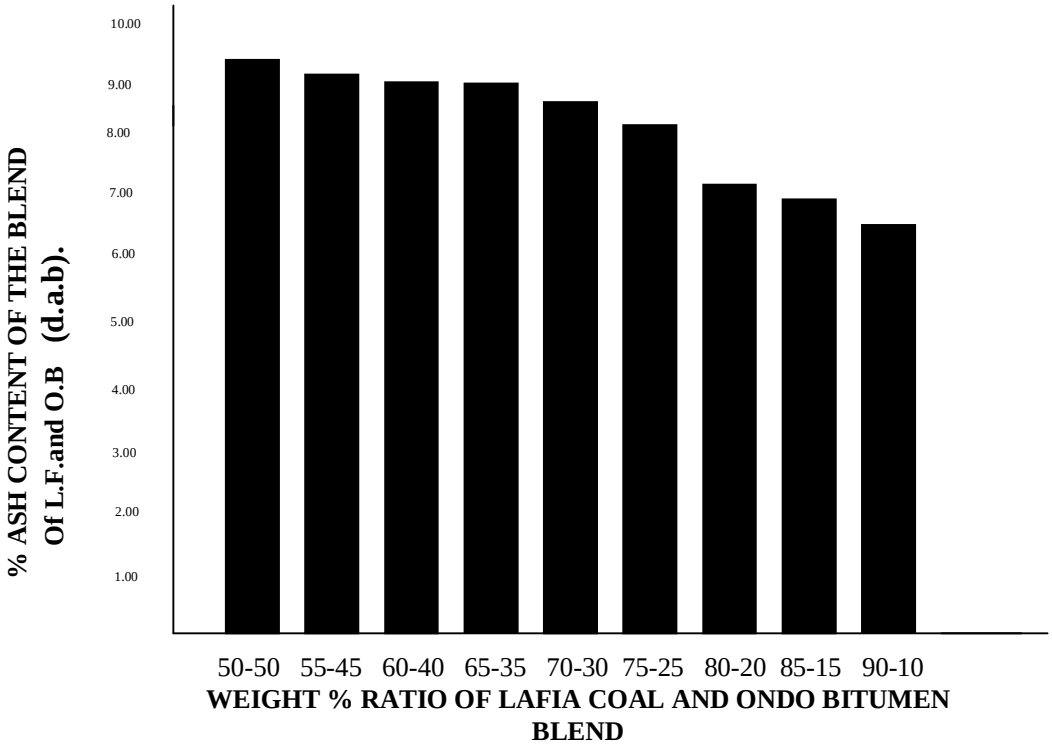


FIGURE 4.3 Influence of bitumen on the ash content of Lafia coal.

Ash content of Lafia Coal =19.21 (D.A.B)

BLAST FURNACE SPECIFICATION: The ash content of coals used for blast furnace usually ranges between 5.0-8.5 % (D.A.B) (Wilson and Wells, 1975).

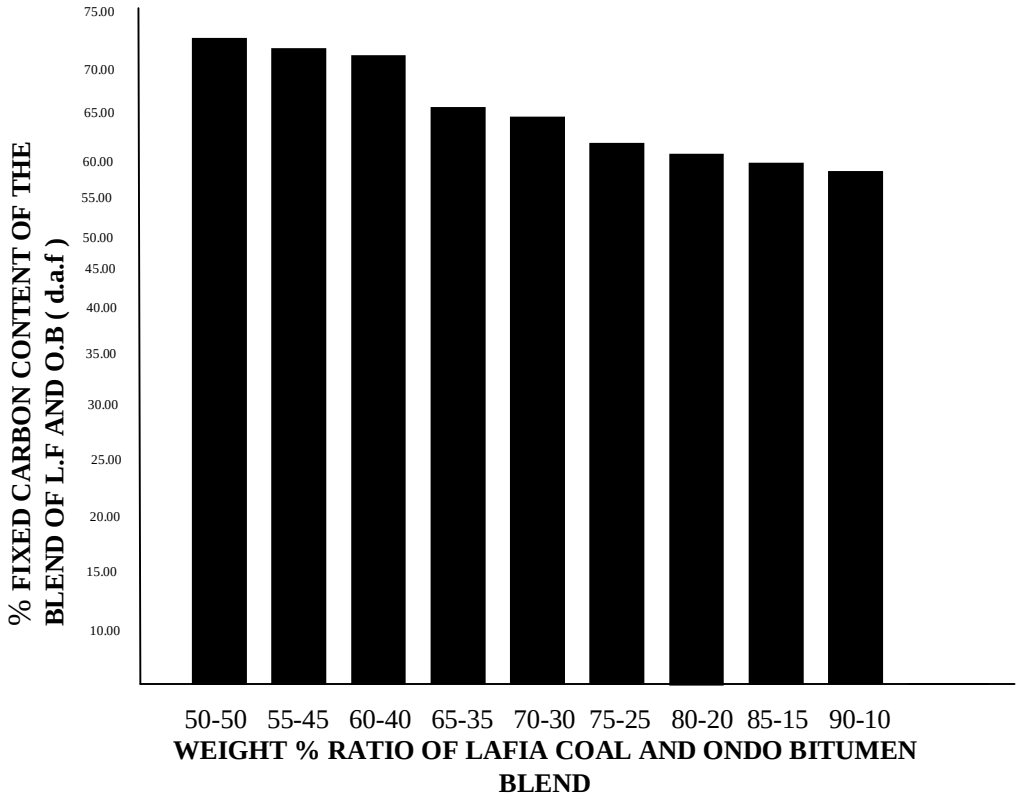


FIGURE 4.4 Influence of bitumen on the fixed carbon content of Lafia coal.

Fixed carbon content of Lafia coal = 57.84 (D.A.F)

BLAST FURNACE SPECIFICATION: The fixed carbon content of coals used for blast furnace usually ranges between 60-90% (D.A.F). (Wilson and Wells, 1975)

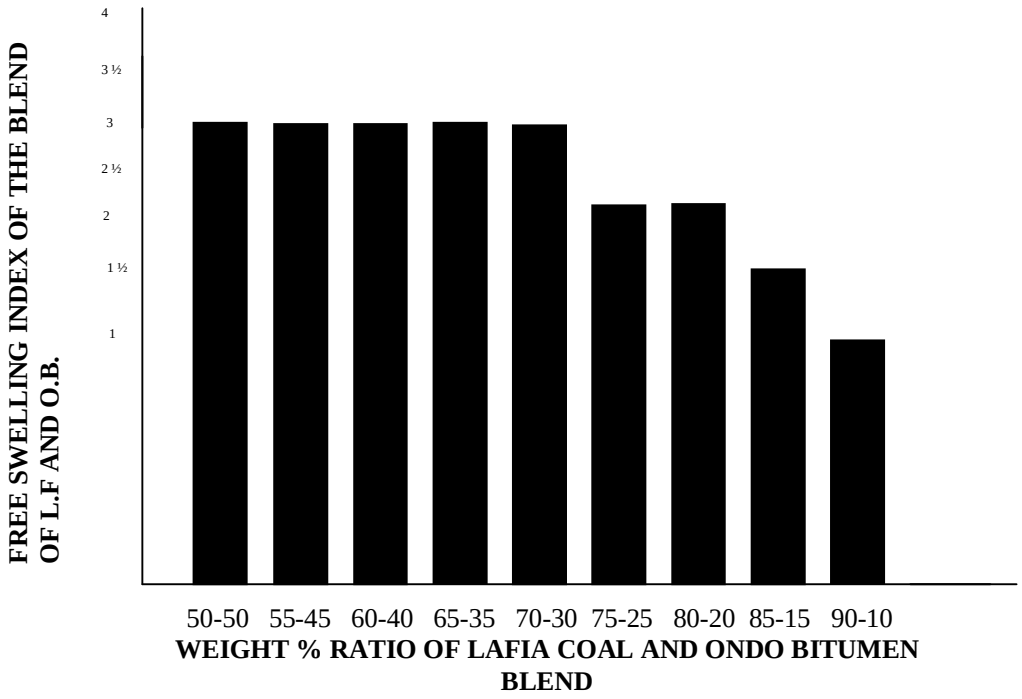


FIGURE 4.5 Influence of bitumen on the free swelling index of Lafia coal.

Free swelling index of Lafia coal. = ½

BLAST FURNACE SPECIFICATION: The Free swelling index of coals used in blast furnace ranges between 3-4 (Wilson and Wells, 1979).

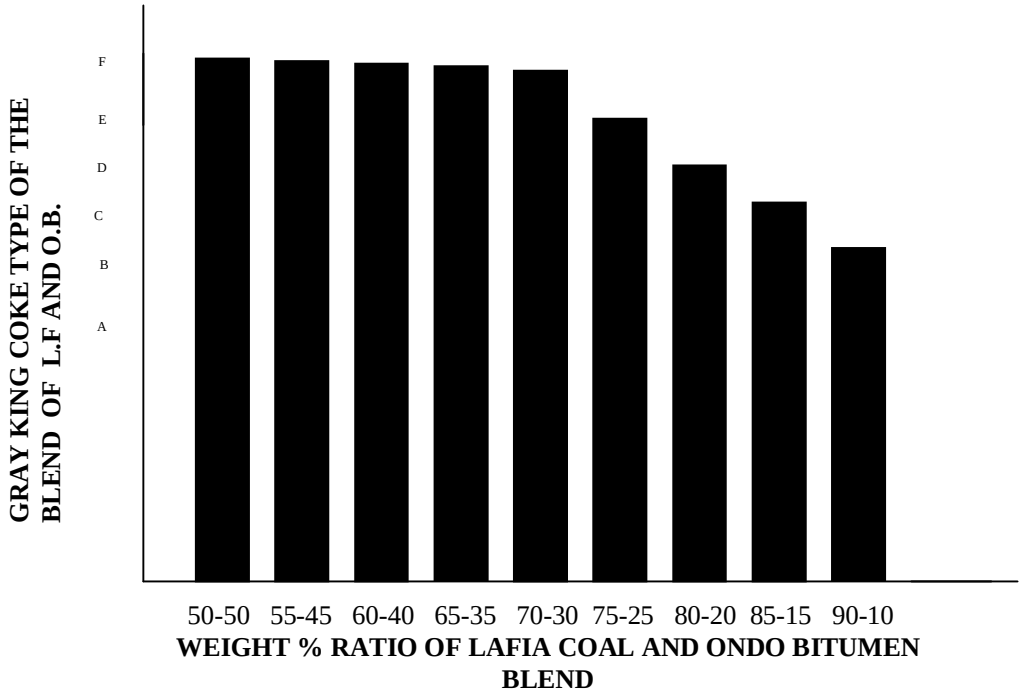


FIGURE 4.6 Influence of bitumen on the Gray-king coke value of Lafia coal.

GRAY- KING COKE VALUE OF LAFIA COAL = B

BLAST SPECIFICATION: The Gray king type for blast furnace ranges from G and above (Wilson and Wells, 1975).

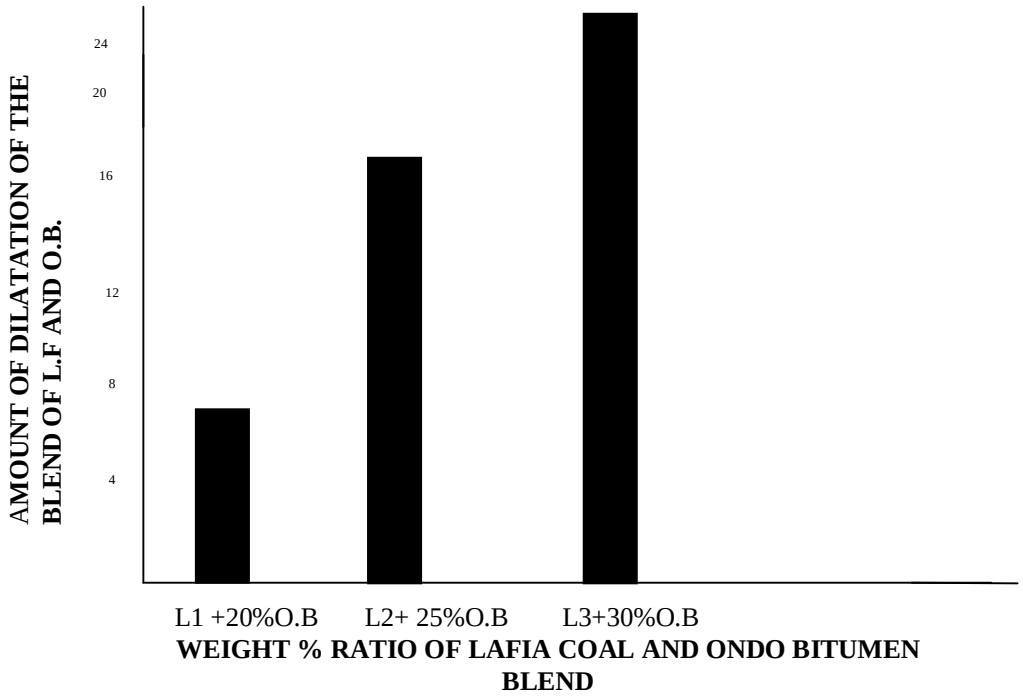


FIGURE 4.7 Influence of bitumen on the dilatation properties of Lafia coal.

4.1 DISCUSSION.

Results obtained are shown in figures 4.1 to 4.7, the blast furnace specification would be used to access the characteristics of the blended Lafia coal and Ondo bitumen.

4.1.1 MOISTURE CONTENT.

From the result obtained, Lafia coal has an average moisture content of 8.96% air dried. Blending of Lafia coal with bitumen resulted in considerable reduction of moisture content at the various percentage ratio used for the blend.

Blending at 90 – 10% (Lafia coal and Ondo bitumen) gave percentage moisture of 2.10%. 85-15% gave a percentage of 2.05%. 80-20% ratio of coal and bitumen gave 2.00%. 75-25% produces 1.95%.70-30% gave 1.89%. 65-35% produced 1.82% moisture content. 60-40% gave 1.78%, 55-45% of coal and bitumen produced 1.70%.

As more bitumen was added to the coal, moisture content reduced. This could be attributed to the fact that bitumen contains little or no water (Owolabi, 1997).

The values are less than the blast furnace specification which is (1.9%) maximum (D.A.B), hence any given ratio could be used in the blast furnace based on moisture content.

It is pertinent to note that moisture is present in coal in the following forms. Surface, inherent and combined.

4.1.2 VOLATILE MATTER CONTENT.

Analysis of the blend of Lafia coal and bitumen showed that the percentage of volatile matter decreased from 36.87% to 24.26% as the quantity of bitumen was increased from 10 to 50%. This could be attributed to the fact that bitumen contains little volatile matter (Table 4.1)

It has earlier been stated that volatile matter content in coal should not be greater than 32%. Thus all ratios (Lafia coal-Ondo bitumen) met the requirement of the blast furnace coke.

4.1.3 ASH CONTENT.

Ash is the incombustible material that remains after a coal is burnt. It lowers the calorific value of the coal (Gibson, 1997). Ash may be inherent or accidental depending on the source from which it is derived. Inherent ash is present in the original vegetable matter from which the coal is formed and is inseparable from the coal substance. It consists of oxides of potassium, sodium, magnesium, calcium and silicon.

From this, it is obvious that ash content is directly related to the mineral matter content.

Accidental ash is dirt and consists of various materials such as clay, shale’s etc. Lafia coal has high ash content but addition of bitumen up to 30%

reduced the ash content to 8.21% (D.A.B), which is within the acceptable limit of the blast furnace coke. A further increase of bitumen beyond 30% showed an increase in the ash content of the blend. This is because bitumen contains ash, thus it is not advisable to increase bitumen beyond 30% in the blend.

4.1.4 FIXED CARBON

From the obtained result, the fixed carbon content increased as the bitumen in the blend was increased i.e. from 59.20% to 72.22% (D.A.F). This increase became minimal, as the bitumen was increased beyond 35%. The increase in fixed carbon content of the blend could be attributed to the carbon present in bitumen. This value of 72.22% (D.A.B) is within acceptable value for production of blast furnace coke (i.e. 60-90% (D.A.B.) (Wilson and Wells, 1975).

4.1.5 FREE SWELLING INDEX

This is another important parameter in selecting a coal for use in the blast furnace. Addition of up to 30% also improved the free swelling index of Lafia coal from ½ to 3, thus increasing its cokability. This could be due to the swelling nature of bitumen, hence any given ratio from 30 to 50 % could be used in the blast furnace based on free swelling index. A proto type test showed that beyond 30 % the coke would be weak and would not support the load imposed within the blast. Hence it is not advisable to increase bitumen beyond 30% in the blend.

4.1.6 GRAY KING COKE TYPE

As mentioned earlier, the gray king value shows whether a coal is coking or not. Addition of bitumen up to 30% improved the gray – king coke value from B to F, thus enhancing its coking properties. The cokes produced from 30% to 50% of bitumen were slightly shrunken and hard. This is because bitumen provides the coal a plastic phase to overcome any diffusional restrictions on the flow and coalescence of metaphase and wets the surface of inert macerals (Pinot and Gorin, 1982). Bitumen provided excellent binding properties toward the inert macerals of the coal thus showing appreciable penetration into the cell cavities of the coal (Yudkoff, 1987). Furthermore bitumen has been found to react with oxidized vitrinite thereby interacting with inert – macerals. The penetration into the inert macerals and the interaction with oxidized vitrinite added to the overall strength of the coke obtained from the blend, thus improving its coking properties in particular Gray – king value.

4.1.7 DILATOMETRY VALUE

This is also an important property to be considered for selecting a coal for use in blast furnace. Form the obtained results, addition of bitumen up to 30% increased the dilatometry value from flat dilatation value of 0 to +24% for 70 30% blend. This is because bitumen possesses good coefficient of volume expansion. This dilatometry value of +24 % is within the blast furnace specification (20 to 27%) for good coking coal. (Damisa, 2001). Hence Ajaokuta blast furnace could utilize the 70- 30 % blend.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The following conclusions could be drawn from the research.

1. The moisture content of Lafia coal fell within the limit desired for coking coals, as already noted, only Lafia coal is slightly coking. The addition of bitumen reduced the moisture content of Lafia coal from 8.86% to 1.89% at 70-30% ratio (Lafia coal – Ondo bitumen).

Coals vary widely in ability to make coke, also bitumen should contain no water, as it will be difficult for bitumen to displace water and adhere to the aggregate. If water is present in bitumen it will foam when heated above boiling point.

2. Volatile matter forms a very important basis for coal classification. Most classifications are based on volatile matter content within the range of 28-33%. The volatile matter content of the blend fell within the specified standard of blast furnace coke (32% max.)

3. The ash content at 70-30% of blend of the coal and bitumen is within the accepted range of the blast furnace specification (8.5% max (D.A.B).)

4. The amount of fixed carbon in coal depends on the type of coal. It increases in rank in passing from lignite to anthracites. The amount therefore

provides an important basis for classification. As the rank increase the coking power rises to a maximum.

On the dry, ash –free basis (daf) the higher the fixed carbon (daf) the higher the rank. This fact has been established in figure (4.4) where it was seen that Lafia coal has a high value of fixed carbon being slightly coking. The addition of bitumen increased the fixed carbon content of Lafia coke from 57.87% (d.a.f) to 68.76% (d.a.f) for 70-30 ratio of Lafia coal and Ondo Bitumen.

5. The Gray king coke type of Lafia coal was influenced from B to F by the addition bitumen from 30% to 50%.

6. Addition of bitumen from 30% to 50% improved the swelling index of Lafia coal from ½ to 3.

7. The dilatometry value of Lafia coal was enhanced from flat dilatation value of 0 to +24 upon the addition of bitumen.

From the work the following conclusions may be made. The Lafia – obi coal is bituminous, and slightly coking. The ash content can be reduced by blending with bitumen. Microscopic examination conducted showed that the coal contains high volatile matter (33% d.a.f) and it can also be reduce by blending with bitumen since the research showed that the volatile matter content decreased as bitumen addition increased i.e. from 30.32% volatile matter of Lafia coal to 27.55% for 70-30% of Lafia coal and Ondo Bitumen.

Blending the coal with Ondo bitumen coupled with improvement treatment will produce a concentrate that can form major blending components with some very high coking coals.

The improvement of the property of Lafia coal from a flat dilation value of 0% to +24 for (70% -30%) ratio showed clearly the significant improvement in cokability of weakly coking coals upon the addition of bitumen, hence with the established availability of abundant reserves of bitumen in Ondo State, the possibility of increasing the coking properties of Lafia coal in blending with bitumen for Ajaokuta blast furnace is therefore encouraged.

5.2 RECOMMENDATION

It is recommended that, Lafia coal and bitumen should be blended with little percentage of prime coking coal to achieve acceptable properties for blast furnace coke production .Also recommended, is addition of inert materials to the coal matrix to study the effects on strength. 70 – 30% ratio of Lafia coal and Ondo bitumen is recommended as a blend ratio for coke production, since it met the standard requirement for blast furnace coke.

TABLE 5.1 STANDARD PROPERTIES OF COKING COALS.

1.	PROXIMATE ANALYSIS	
	Moisture content	1.9% max. d.a.b.
	Volatile matter (d.b.)	22 – 32%.
	Ash (d.b.)	8.5% max.
	Phosphorous	0.2%
	Sulphur	0.7% max.
	Fixed carbon	By difference.
2.	COKING PROPERTIES.	
	Gray king coke type	G and above.
	Crucible swelling index	3-4 minimum.
	Coking Index (BSS).	22 min
	Mean max. reflection on vitrinite	More than 10%
	Hardgrove grindability.	70min.
	Quality of coke to be produced from the coal.	
	Ash	13%
	Mecum strength in M40	78% min
	Volatile matter	1.5%
	Sulphur	1.2%
	Moisture	1-4%

Source: (NMDC, Jos 2001).

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TABLE A1 MOISTURE CONTENT OF LAFIA COAL AND THE BLEND OF LAFIA COAL AND ONDO BITUMEN.

Samples.	M_1(g)	M_2(g)	M_3(%)
Lafia Coal.	1.000	0.086	8.96
Blend of L.F - O.B 90 - 10	1.000	0.0210	2.10
85 - 15	1.000	0.0205	2.05
80 - 20	1.000	0.0200	2.00
75 - 25	1.000	0.0195	1.95
70 - 30.	1.000	0.0189	1. 89
65 - 35	1.000	0.0182	1.82
60 - 40	1.000	0.0178	1.78
55 - 45	1.000	0.0175	1.75
50 - 50	1.000	0.0170	1.70

NOTE: M_1 = weight of the sample before heating.

M_2 = weight of the sample after heating.

M_3 = % weight of Moisture of coal/blend.

BLAST FURNACE SPECIFICATION: Moisture content of blast furnace coke should be below 5% (Chung and Geer, 1979)

TABLE A.2: VOLATILE MATTER CONTENT OF LAFIA COAL AND THE BLEND OF LAFIA COAL AND ONDO BITUMEN.

Samples.	**W_a(g)**	**W_b(g)**	**W_c(%)**	**% Volatile matter content D.A.B**
Lafia Coal.	1.000	0.2764	27.64	30.32
Blend of L.F - O.B				
90 – 10	1.000	0.3610	36.10	36. 87
85 - 15	1.000	0.3580	35.80	36.54
80 - 20	1.000	0.3552	35.52	33.24
75 - 25	1.000	0. 3332	33.32	33.98
70 - 30.	1.000	0.2755	27.55	28.08
65 - 35	1.000	0.2608	26.08	26.56
60 - 40	1.000	0.2542	25.42	25.88
55 - 45	1.000	0.2542	25.01	25.45
50 - 50	1.000	0.2426	24.26	24.69

NOTE: W_1 = weight of the sample before heating.

W_2 = weight of the sample after heating.

W_3 = % weight of volatile matter of coal/blend.

4.2.1 BLAST FURNACE SPECIFICATION: the volatile matter content of coal used for blast furnace usually range between 23 –32 % [D.A.B] (Wilson and Wells, 1975)

TABLE A3: ASH CONTENT OF LAFIA COAL AND THE BLEND OF LAFIA COAL AND ONDO BITUMEN.

Samples.	**a_1(g)**	**a_2(g)**	**a_3 (%)**	**% Ash content. D.A.B**
Lafia Coal.	1.000	0.1751	17.51	19.21
Blend of L.F - O.B				
90 - 10	1.000	0.06105	6.15	6.25
85 - 15	1.000	0.0627	6.27	6.58
80 - 20	1.000	0.0645	6.45	
75 - 25	1.000	0.0725	7.25	7.39
70 - 30.	1.000	0.0805	8.05	8.21
65 - 35	1.000	0.0895	8.95	9.12
60 - 40	1.000	00913	9.13	9.30
55 - 45	1.000	0.0921	9.21	9.38
50 - 50	1.000	0.0924	9.24	9.40

BLAST FURNACE SPECIFICATION: the ash content of coal used for blast furnace usually range between 5.0–8.5% [D.A.B] (Wilson and Wells, 1975)

TABLE A.4: FIXED CARBON CONTENT OF LAFIA COAL AND THE BLEND OF LAFIA COAL AND ONDO BITUMEN.

Samples.	**% FIXED CARBON (AIR –DRY)**	**% FIXED CARBON (AIR –ASH FREE)**
Lafia Coal.	41.61	57.84
Blend of L.F - O.B		
90 – 10	53.73	59.20
85 - 15	54. 32	59.69
80 - 20	55.18	60.35
75 - 25	56.68	62.52
70 - 30.	61.82	68.76
65 - 35	62.50	70.17
60 - 40	63.04	70.89
55 - 45	63.42	71.36
50 - 50	64.21	72.22

BLAST FURNACE SPECIFICATION: The fixed carbon content of coal used for blast furnace usually range between 60–90% [D.A.F] (Wilson and Wells, 1975)

NOTE: FC (Daf) = 100X FC ad / 100 – (% ash + % Moisture content (dry)

TABLE A.5 : FREE SWELLING INDEX OF LAFIA COAL AND THE BLEND OF LAFIA COAL AND ON DO BITUMEN.

Samples.	**C_1(g)**	**C_2(g)**	**C_3(%)**	**Free Swelling Index.**
Lafia Coal.	1.000	0.928	92.8	½
Blend of L.F - O.B				
90 - 10	1.000	0.865	86.5	1
85 - 15	1.000	0.855	85.5	1 ½
80 - 20	1.000	0.839	83.9	2
75 - 25	1.000	0.866	86.6	2
70 - 30.	1.000	0.872	87.2	3
65 - 35	1.000	0.894	89.4	3
60 - 40	1.000	0.909	90.9	3
55 - 45	1.000	0.929	92.9	3
50 - 50	1.000	0.935	93.5	3

Note: C_1 = weight of sample used

C_2= average weight of coke

C3 = % weight of coke.

4.5 .1 BLAST FURNACE SPECIFICATION: The free swelling index of coal used in blast furnace ranges between 3 - 4 (Wilson and Wells, 1975)

TABLE A.6 GRAY KING COKE TYPE OF LAFIA COAL AND THE BLEND OF LAFIA COAL AND ONDO BITUMEN

Samples.	**W_1(g)**	**W_2(g)**	**W_3(%)**	**Gray- king coke Type.**
Lafia Coal.	10.00	9.45	94.5	B
Blend of L.F - O.B				
90 - 10	10.00	8. 71	87.1	B
85 - 15	10.00	8. 65	86.5	C
80 - 20	10.00	8. 55	85.5	D
75 - 25	10.00	8. 54	85.4	E
70 - 30.	10.00	8. 53	85.3	F
65 - 35	10.00	8. 41	84.1	F
60 - 40	10.00	7. 82	78.2	F
55 - 45	10.00	6. 84	68.4	F
50 - 50	10.00	5. 85	58.5	F

Note: W1 = weight of sample used
W2= average weight of coke
W3 = % weight of coke

4.5 .1 BLAST FURNACE SPECIFICATION: The Gray king coke type for blast furnace ranges from G and above (Wilson and Wells, 1975).

TABLE A.7 DILATOMETRY OF LAFIA COAL AND BLEND OF LAFIA COAL AND ONDO BITUMEN.

S/N	SAMPLE	MAXIMUM CONTRACTION (%)	SOFTENING TEMP. (º C)	AMOUNT OF DILATATION. (%)
1	LAFIA (L_1)	-15	180	0
2	LAFIA (L_2)	-14	182	0
3	LAFIA (L_3)	-13	186	0
4	L_1+20% BITUMEN	-11	203	+ 6
5	L_2 + 25% BITUMEN	-9	210	+16
6	L_3+ 30% BITUMEN	-8	216	+ 24

NOTE: L_1= 80% Lafia coal , L_2 = 75% Lafia coal and L_3 = 70% Lafia coal

A.8 SHATTER AND ABRADABILITY TESTS FOR 70-30 % BLEND RATIO OF LAFIA COAL AND ONDO BITUMEN

Shatter Test -50%

Abradability - 10%

TABLE A.8. SUMMARY OF RESULTS.

SAMPLE	F.S.I	G.K COKE TYPE	% MOISTURE A.D	% VOLATILE MATTER (D.A.B)	% ASH D.A.B	% FIXED CARBON D.A.F	AMOUNT OF DILATATION
LAFIA	½	**B**	**8.86**	**30.32**	**19.21**	**57.84**	**0**
Blend of L.F - O.B							
90 - 10	1	**B**	2.10	36.54	6.25	59.20	nd
85 – 15	1 ½	**C**	2.05	36.53	6.43	59.69	nd
80 - 20	2	**D**	2.00	36.52	6.58	60.35	+ 6
75 - 25	**2 ½**	**E**	**1.95**	**33.32**	**7.39**	**62.52**	**+ 16**
70 -30	**3**	**F**	**1.89**	**27.55**	**8.21**	**68.76**	+ 24
65 - 35	**3**	**F**	**1.82**	**26.08**	**9.12**	**70.17**	nd
60 - 40	**3**	**F**	**1.78**	**25.42**	**9.30**	**70.89**	nd
55 - 45	**3**	**F**	**1.75**	**25.01**	**9.38**	**71.36**	nd
50 - 50	**3**	**F**	**1.70**	**24.26**	**9.40**	**72.22**	nd
BLAST FURNACE SPECIFICATION.	**3 (minimum)**	**G – G9**	**Below 5%**	**23-32**	**5.0-8.5**	**60-90**	**Minimum - 6**