

Quality of some Nigerian coals as a blending stock in metallurgical coke production.

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ABSTRACT

Two Nigerian coals, Lafia-Obi and Chikila were blended in the mass ratio of 70:30 with imported American and Polish coking coals. Proximate analysis, free swelling index, Ruhr dilatometer and Gieseler plastometer were used in accessing the coking qualities of both the single coals and the blends. The results showed that the blends are lower in moisture and ash contents; higher in volatile matter and fixed carbon than the single Nigerian coals. The rheological parameters revealed superiority in thermo-plastic properties of the blends over the unblended local coals. Lafia-Obi/foreign coals blends possess lower ash and better rheological properties compared to Chikila/foreign coal composites which have high ash and poor rheological properties. These together suggest that amongst the two Nigerian coals, Lafia-Obi is superior for blending with the foreign ones in metallurgical coke making.

1.0 INTRODUCTION

The importance of coal in the energy mix of Nigeria and the entire world cannot be underestimated. Coal was first discovered in Nigeria near Udi, by the Mineral Survey of Southern Nigeria in 1909 and its belt spans through a considerable part of the country¹. The actual production commenced in 1916 with 24 000 tons for that year and recorded a cumulative output of 22.9 million tons by 1967 when production ceased as a result of the Nigerian Civil War². Since then production has been epileptic. Presently the only exploited coal deposits are those of Okaba, Onyeama, Okpara and Okwukpa which are mainly used for combustion, fuel, electricity etc³. Coking coal is required for coke and can serve the blast furnace of Ajaokuta Steel Company. But most of the Nigerian coals are non-coking types⁴. As part of the Nigerian government economic reform, the Federal Ministry of Solid Minerals Development was established and coal was listed as one of the priority minerals targeted for exploration and exploitation for export and domestic consumption.

Coal can transform into coke only if it softens to a plastic mass on carbonization, followed by decomposition, swelling and evolution of gas and finally resolidification while gas is still being evolved⁵. Coke quality has long been a major concern to the steel industry. The quality of coal determines to a large extent the quality of the resulting coke. Some coals possessing some of the coking properties may lack others, and may even be detrimental to the coke ovens.

In the past, coke-makers relied on medium-volatile bituminous coals⁶, but due to their scarcity and high price, coking coals of this rank are typically used as a 'base' in blends, to which coals of differing rank and chemical properties are added in such a way that, overall, the blend achieves the required coke quality^{7,8,9}. Impurities present in coal would end up in coke and this would affect its performance in the blast furnace. This is by decreasing its role as a fuel in terms of amount of carbon available for direct and indirect reduction roles and also its role as a permeable support. Such impurities are moisture, volatile matter, ash, sulfur, phosphorus, and alkali contents¹⁰. Their desired contents can be achieved easily by suitably proportioning different coals in the blend. Impurities like sulfur, phosphorus and alkalis in coke can be minimized by limiting these constituents in the individual coals. One measure of coal's ability to make good quality coke is fluidity, a measure of the rheological properties¹¹. These properties can be studied during coke formation by monitoring the length of a pressed specimen of powdered coal in a dilatometer, such as the Audibert-Arnu or the Ruhr dilatometer, or by measuring the viscosity, or fluidity, of a pressed coal powder in a Gieseler or Hoehne plastometer as the coal is heated over its carbonization range. Note is taken of the temperature at which critical stages of the carbonization process are reached and of the degree of change, such as contraction, expansion, or fluidity, which develops in the material as the coke is formed. These data can then be used in various ways to assess the suitability of a coal or blend of coals for coke manufacture.

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In the search for a Nigerian coking coal, Aderonpe¹² carried out the assessment of blends of high volatile (30% - 36%) bituminous coals with low volatile (<20%) bituminous. In another investigation, Onyeama and Okaba coals were reported to be poorly caking, while Lafia/Obi as weakly caking¹³. The Cakability of Enugu coal blended with some imported coals was also studied¹³.

This paper reports the blending and quality assessment of some Nigerian coals with American and Polish coking coals. Some parameter that determined coking quality like the proximate analysis, free swelling index, Ruhr dilatometric and Gieseler plastometric properties were used in accessing the suitability of the blends for metallurgical coke production.

EXPERIMENTALS

Materials

The coal samples were obtained from the National Metallurgical Development Centre (NMDC), Jos, Nigeria. The local coals were Chikila and Lafia-Obi (Lafia); while the foreign ones were American and Polish coals. The samples were pulverized and sieved using a 200 mesh British standard (Merck brand). A 70:30 mass ratio of foreign to local coals were used in the blends. The major instruments used for the analysis were Leco Digital Balance (LECO 250), Gray King Furnace (11/81/1085), Ruhr Dilatometer (205DIG), Gieseler Plastometer (42000/A4) and a Phoenix furnace (MK 2000/45)

Proximate analysis

Proximate analyses of the coals were performed based on ASTM Standards¹⁴ as showed below. All runs were repeated to check the instrument's reproducibility.

Volatile Matter Content

Coal passing through 200 mesh BS sieve was heated for 7 minutes at 900°C out of contact with air. The volatile matter was calculated from the loss in mass of the sample less the loss in mass due to the moisture content according to the formula:

$$V_m = 100 - (m_1 - m_2) / m_1 - m_2 - M$$

Where,

V_m = Volatile Matter

m_1 = initial mass of crucible plus sample

m_2 = mass of crucible plus residue of sample after heating

M = Moisture Content.

Moisture content

1.0g of sample was loaded into a heating crucible and placed for one hour in an oven that has been pre-heated to 110°C. The crucible was then taken out of the oven and left to cool before it was weighed again. The moisture content was calculated according to the following formula:

$$[(A - B)/A] \times 100$$

Where,

A = Mass of Sample Used (Before heating)

B = Mass of Sample after heating.

Ash Content:

1.0g of the sample was loaded into a cold crucible and placed in a cold oven. The oven was heated at a rate to reach 500°C in 1 hour. It was then heated further at a lower rate to reach 750°C after the second hour. The oven was kept stable for another 2 hours between 700°C and 750°C. The crucible was removed from the oven and cooled to room temperature and weighed again. The ash content was calculated according to the following formula:

$$\text{Ash in Sample} = [(A - B)/C] \times 100$$

Where,

A = Mass of the crucible, cover and Ash residue

B = Mass of empty crucible and cover

C = Mass of analysis sample used.

Free swelling index determination

1g of coal sample was taken into a porcelain crucible; it was covered and heated for seven (7) minutes on a Bunsen burner. After cooling, the bottom cake was compared with a standard profile numbered from 1-9 (Table 2).

Gray king (profiles) determination

10g of the sample was spread over a 15cm length horizontally placed retort tube. The tube's end was plugged with cotton wool and transferred into a furnace set at an initial temperature of 325°C. The temperature was gradually increased to 600°C. The retort tube was removed after 15 minutes and allowed to cool. The carbonized coal in the retort was compared with the standard Gray King profiles (Figure 1).

Ruhr dilatometric and Gieseler plastometric properties

The Ruhr Dilatometric (Table 2) and Gieseler Plastometric (Table 3) Properties were determined based on ASTM standards¹⁴.

RESULTS AND DISCUSSION

The results obtained from the proximate analysis of the individual coals and those of the blends are shown in Table 1 on three (3) replicates. The moisture and ash contents of the Lafia-Obi (2.91%; 8.7%) and Chikila coals (5.82%; 14.9%) are higher than the American (1.07%; 5.77%) and Polish coals (0.58%; 4.79%). On blending, a reduction in moisture and ash contents of the blends compared to the single Nigerian coals was observed. The reduction in moisture content represents a significant improvement in coal's quality because moisture affects the calorific value and the concentration of other constituents¹⁵. Likewise the reduction in ash content is an improvement on the coking quality, low ash content is an essential requirement for coke making coals. Because some of the ash would end up in the coke on carbonization, in the blast furnace, the ash influences slag volume and composition. An ash content of less than 10% is recommended for a good coking coal¹⁶. Industrial experience indicates that a 1 wt. % increase of ash in the coke reduces metal production by 2 or 3 wt. %¹⁰.

The volatile matter of Chikila coal (44.27%) is higher than that of Lafia-Obi (29.39%), American (31.36%) and the Polish coal (32.61%). Lafia-Obi has the lowest volatile matter amongst all the coal samples. The volatile matter of Lafia-Obi coal is close to that of the foreign coals; while a large difference exists between Chikila coal and the foreign ones. It was observed elsewhere that the Lafia-Obi coal is higher in maturity than the Chikila coal¹⁷ and volatile matter is known to decrease with increase in rank^{18,19}.

Therefore it is not surprising that the volatile matter of Lafia-Obi is lower than that of Chikila. The volatile matter of the Lafia-Obi/foreign coal blends are close to that of the single Lafia-Obi coal while the volatile matter of the Chikila/foreign coals blends is slightly lower than that of Chikila and significantly higher than those of foreign coals. Volatile matter, apart from its use in coal ranking, is one of the most important parameters used in determining their suitable applications²⁰. Volatile matter does not form part of the coke; it is usually evolved as tar during carbonization⁴. High-volatile bituminous coal due to its high volatile matter content generates high pressure during carbonization which is detrimental to the coke oven walls^{4,7,21}. Therefore the Lafia/foreign coal blends may be expected to have better coking qualities than the Chikila/foreign coal blends.

The fixed carbon of the Lafia-Obi (61.93%) and Chikila (40.83%) coals are lower than that of American (62.87%) and Polish (62.60%) coals. There is no significant difference between the fixed carbon content of Lafia-Obi and the foreign coals and a large difference between the fixed carbon content of Chikila and the foreign coals. The fixed carbon content of Lafia-Obi/American (62.21%), Lafia-Obi/Polish (62.13%), Chikila/American (47.77%) and Chikila/Polish (47.69%) are generally higher than the single Nigerian coals. These show an improvement in the fixed carbon content hence the coking quality. The carbon content of a coal is essential in coke making because it is the mass that forms the actual coke¹⁹. The Lafia-Obi/foreign coals blends have higher carbon content and may form better coke than the Chikila/foreign coals blends.

Table 2 shows the free swelling indices (FSI) of the single coals and the blends. The crucible swelling number depends on both rank and coal type. If a single coal is to be used for coke manufacture, an intermediate value (4-6) for this parameter is probably desirable, since a coal with a low swelling number will have adequate porosity, while one with a high swelling number will not have adequate strength^{5,19}. Lafia-Obi, American and Polish coals show an agglomeration behavior with free swelling indices of 4½, 4½ and 6; and a corresponding Gray – King Coke types of G₃, G₂ and G₃ respectively. The profiles obtained are shown in Figure 1. Chikila coal is of poor caking quality with FSI of ½ and Gray-King coke profile of A, the profile is non-coherent (Figure 1). The Free Swelling Index and Gray King coke types of all the blends are greater

than those of the single Nigerian coals with the exception of Lafia/American blend which remain the same (FSI = 4½; Gray-king coke type = G3). The highest improvement is observed between Chikila coal and the Chikila/Polish composite, the FSI improved from ½ to 1½ and Gray-king coke type from A to C. the letters A and C indicate non-caking and very weakly caking coals respectively. While letters G₁-G₉ signifies medium to strongly caking coals. The superscript shows the number of electrode carbon in the particular coal.

The Ruhr Dilatometric Properties of the coal samples are also shown in Table 2. It can be seen that the

Lafia/Obi coals softens at 340°C and contracts maximally at 467°C with maximum dilation of 9%. This is a good plasticity behavior expected of a coking coal; the value is also in agreement with the observed FSI. On the other hand, Chikila coal also softens at 340°C with a maximum contraction temperature of 425°C and zero dilation. American coal and Polish coal softened at 370°C and 386°C with maximum dilatation temperatures of 468°C and 440°C and maximum dilatation of 119% and 16% respectively. The softening temperature, contraction temperature and dilation of the blends are generally greater than those of the Nigerian coals (Table 2).



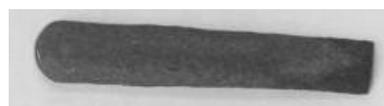
(1a)



(1b)



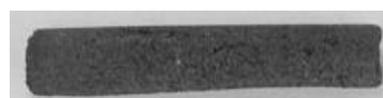
(2a)



(2b)



(3a)



(3b)



(4a)



(4b)

Figure 1: Photographs of Gray-King coke profiles obtained from samples; (1a) Lafia-Obi (1b) Chikila (2a) American (2b) Polish (3a) Lafia/American (3b) Lafia/Polish (4a) Chikila/American (4b) Chikila/Polish

Table 1: Proximate analysis of the coals showing the composition of moisture, ash, volatile matter and fixed carbon of samples

Proximate analysis	Lafia	Chikila	American	Polish	Lafia/ American	Lafia/P olish	Chikila/ American	Chikila/ Polish
Moisture content (wt %)	2.91	5.82	1.07	0.58	2.31	2.09	4.38	4.23
Volatile matter (% db)	29.37	44.27	31.36	32.61	29.97	30.34	40.40	40.77
Ash content (% db)	8.70	14.90	5.77	4.79	7.82	7.53	12.16	11.87

Table 2: Free swelling index, Gray King coke types and Ruhr dilatometric properties of samples

Parameters	Free swelling index	Gray-King coke type	Ruhr Dilatometric Properties							
			Initial Temp. °C	Softening Temp. °C	Initial Contraction Temp. °C	Max. Contraction Temp. °C	Max. Dilatation Temp. °C	Max. Dilation (%)	Max. Contraction (%)	Heating Rate (°C/min)
Lafia	4½	G ₃	300	340	420	407	486	9	-6	3
Chikila	½	A	300	340	350	425	442	Nil	-9	3
American	4½	G ₂	330	370	410	468	468	16	-30	3
Polish	6	G ₃	350	386	390	424	440	119	-29	3
Lafia/American	4½	G ₃	320	360	420	435	476	12	-8	3
Lafia/Polish	4½	G ₄	317	364	420	432	477	38	-5	3
Chikila/American	1	B	310	350	365	430	450	4	-14	3
Chikila/Polish	1½	C	315	355	362	425	442	18	-12	3

Table 3: Gieseler plastometric properties of samples

Parameter	Lafia	Chikila	FAM	FPL	Lafia/FAM	Lafia/FPL	Chikila/FAM	Lafia/FPL
Softening temperature °C	330	270	390	395	348	350	306	308
Max. fluidity temp. °C	367	340	435	445	388	391	369	372
Max. fluidity (DDPM)	310	298	342	456	320	354	308	342
Resolidification temp. °C	394	336	458	485	413	422	372	381
Temperature range °C	64	66	68	90	65	72	66	73

DDPM = Dial Division Per Minute

Amongst the blends Chikila/Polish recorded the highest dilation value of 38(%) which represent a 26(%) increase over that of single Lafia-Obi coal. Chikila coal which shows no dilation at all, recorded dilation values of 4(%) and 18(%) on blending with American and Polish coals respectively. Gieseler plastometric properties of the coals and the blends are shown in Table 3. Lafia-Obi and Chikila coals soften at 330 °C and 270 °C, reaching a maximum fluidity of 310 ddpm and 298 ddpm at a temperature of 367 °C and 340 °C respectively. The blends exhibit higher softening temperature, maximum fluidity temperature and maximum fluidity (320 ddpm and 354 ddpm) than the single Nigerian coals. Fluidity data provide information about the formation of a plastic phase during coke making. Diez et al.¹⁰ reported that a Gieseler maximum fluidity between 200 and 1000 dial division per minute is desirable for a good coking coal blend. Thus the parameters indicate the ability of the coal blends to form a homogeneous solid coke.

5.0 CONCLUSION

The rheological and chemical analyses have shown that the Nigerian coals are poorer in coking qualities than the investigated American and Polish coals. Amongst the Nigerian coals, the qualities of Lafia-Obi are superior to those of Chikila coal. The coking qualities of Nigeria/Foreign coal blends are generally better than those of the single Nigerian coals. Blends produced using Lafia-Obi coal are more qualitative than those produced by Chikila coal. Thus a good metallurgical coking coal may be obtained by blending the Lafia-Obi coal with either the American or Polish coking coals.

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