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A PREDICTION OF MICUM STRENGTH OF METALLURGICAL COKE USING RUHR DILATOMETRIC PARAMETERS OF PARENT COALS

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Abstract

The Polish Bellview, Australian Agro-Allied and American Carbon Energy coals were subjected to Ruhr dilatometric analysis to predict their suitability for cokemaking. The Ruhr dilatometric softening point, maximum contraction, maximum dilatation, maximum contraction temperature and the G-value coking capacities were determined from which G-values of 0.97, 0.93, 0.94 and 1.01 were calculated for Bellview 1, Bellview 2, Agro-Allied, and Carbon Energy respectively. Also, micum 10 indices of 11.40%, 15.40%, 15.40% and 25% and micum 40 indices of 77.80%, 70.80%, 78.20%, and 64.16%, respectively were determined for Bellview 1, Bellview 2, Agro-Allied and Carbon Energy coals. The studies confirmed that Simonis' G-value provides a reliable indication of coke micum strength indices, with the two strength parameters found to be poor at G-values below and above the Simonis' range of 0.95 to 1.15. The analysis results showed that Bellview 1 with the nearly mid-value coking capacity of 0.97 has the best combination of resistance to abrasion and fragmentation.

***Keywords*:** Coals; dilatometry; cokemaking; dilatation; coke.

1. Introduction

Coal is a compact, stratified mass of mummified plant debris, interspersed with smaller amounts of inorganic matter and covered with sedimentary rocks. The rank of a coal is the degree of change of chemical composition of the coal within the series of fossil fuels ranging from the least mature peat to the most mature anthracite[1]. When a bituminous coal is subjected to high temperatures, it undergoes some changes which among others include decomposition into a number of complex compounds, the evolution of various gaseous and condensing substances, conversion into plastic mass at specified temperatures as a result of melting of its bitumen constituents and conversion of the plastic mass formed into non-plastic mass due to further molecular decomposition of the organic mass.

The process described results in the formation of coke, a solid residue having properties suitable for blast furnace ironmaking. Metallurgical coke has a high mechanical strength and abrasion resistance to withstand abrading forces when a column of smelted charge gradually descends in a blast furnace[2]. Dilatometers are used to measure the expansion and contraction of coals when heated. The Ruhr dilatometer, a modified form of Audibert-Arnu dilatometer, gives a coal's initial softening temperature (E), the maximum contraction(c), the temperature at maximum contraction, the maximum contraction temperature, maximum dilatation temperature (V) and the masximum dilatation percent (d). Simonis derived a coefficient G from the co-ordinates of the plastic zone curve, which can be used to predict coke strength. G was defined as[3,4]:

$$G = \frac{E+V}{2} x \frac{c+d}{Vxc+Exd} \quad (1)$$

The micum drum test indices M10 and M40 have been found reliable to indicate the abrasion and fragmentation resistance of metallurgical coke. The aim of this research work is to study the relationship between Ruhr dilatometric parameters and the micum strength of coke produced from coals imported from Australia, Poland and United States for cokemaking at the Ajaokuta Steel Plant, Nigeria.

2. Materials and methods

Samples of Australian Agro-Allied (AA), Polish Bellview (BV) and USA Carbon Energy (CE) received from the Ajaokuta Steel Plant, Nigeria. The coal samples were quartered and representative samples were ground in a mortar to obtain samples passing a 250 micron sieve for the Ruhr dilatometry tests.

For the micum strength tests, the coke sample dropped into a steel receiver from a height of 5m was used. The Ruhr dilatometry test involved sample preparation in which coal pencils were produced and thermoplastic tests in the Ruhr dilatometer according to the description in[5].

In Ruhr dilatometry, the variation in the length of a column of coal during heating is measured[4,5]. The coal sample ground to pass 250 micron sieve was compacted into a pencil form. The pencil of coal was then placed in a metal tube and a piston rod was inserted into the tube to rest on piston's top. The other end of the piston rod was attached to a rotating barrel to record the vertical movement of the piston. On heating, the column of coal softened and contracted in length due to the plastic deformation under the action of piston. When the coal softened, bubbles of gas were evolved causing the coal column to swell up.

The dilatation percent of the coal indicates its coking power. The results of the Ruhr dilatometric analysis are presented in Table 1, while Figures 1, 2 and 3 show the interrelationship between G-values and other dilatometeric parameters.

The coal samples were carbonized by normal charging in a 250-kg capacity coke oven according to German standard described in[6]. Typical normal charging carbonization conditions used were:

- Flue temperature – 1020^{o}C
- Bulk density – 830kg/m^3
- Carbonization period – 15 hours
- Charge temperature – 1250^{o}C

The determination of micum indices involved coke stabilization, coke screening and micum drum test. In coke stabilization, the coke yield was dropped from a height of 5m into a metal receiver once. The stabilized coke was then screened through vibrating round hole screens of sizes <10, 10-20, 20-40, 40-60, 60-80 and > 80mm. For micum drum test, 50 kg of the screened coke was subjected to 25rev/mm for 4min in a steel drum and screened again. The micum 10 (M10) was determined as the percentage of the coke residue below 10mm sieve size and micum 40 (M40) the percentage of the coke residue above 40mm sieve size.

3. Results and discussion

The results of the Ruhr dilatometry and micum drum analyses are presented in Table 1. The results of the dilatometric analysis showed that Bellview 1, Bellview 2, Agro-Allied, Carbon Energy 1, Carbon Energy 2 have maximum contraction percent of 26%, 24%, 22% and 30%, respectively. It is observed that the Agro-Allied coal with the lowest maximum contraction gave the highest micum 40 value of 78.20%, while Carbon Energy coal with the highest maximum contraction yields coke with the least M40 value of 64.16%. It is however noted that M40 index does not generally increase with decreasing value of maximum contraction. Thus, for resistance to shattering or fragmentation, coal blends with low values of maximum contraction may produced coke with the required M40 indices.

Table 1 Ruhr Dilatometric Parameters and micum indices for coals

S/N	Parameters	BV1	BV2	AA	CE1
1.	Softening Temp.°C (E)	406	404	395	408
2.	Temp of maximum contraction °C (E_c)	440	439	424	437
3.	Temp. of maximum dilatation °C (V)	463	462	440	482
4.	Maximum contraction % (c)	26	24	22	28
5.	Maximum dilatation % (d)	10	-7	-8	40
6.	Temp. range °C (E_c-E) (T_1)	34	35	29	29
7.	Temp range °C (V-E_c) (T_2)	23	23	16	45
8.	Temp range °C (V-E) (T_3)	57	58	45	74
9.	Micum 10 (M10)	11.40	15.40	15.40	25.00
10.	Micum 40 (M40)	77.80	70.80	78.20	64.16
11.	G-value	0.97	0.93	0.94	1.01
12.	Total Expansion	36	14	14	68

For the M10 index, the Carbon Energy blend with the highest maximum contraction gave the worst M10 index of 25% (which indicates a coke with very poor abrasion resistance), while coke with the best M10 index of 11.40% was produced by Bellview 1 coal blend with 26% maximum contraction. Thus, the maximum contraction percent parameter gives no clear indication of abrasion resistance, but coal blends with very high maximum contraction may produce coke with very poor abrasion resistance. Thus, coal blends with moderately high maximum contraction percent of about 26% may be more cokeable than those with very high contraction.

The increase in maximum dilatation percent shows reasonable linear relationship with the coke micum strength. It is however noted that Bellview coal 1 with 36% total expansion produced coke with the best combination of M10 and M40 indices of 11.40% and 77.80% respectively, while coke with the worst M10 and M40 combination of 25% and 64.16% respectively, was produced by carbon energy blend with very high total expansion of 68%. It was further observed that Bellview 2 and Agro-Allied blends with only negative dilatations of –7% and –8%, respectively, produced coke with better combination of M10 and M40 when compared with Carbon Energy coal with the high positive dilatation of 40%. It is thus obvious that while moderate positive dilatation is desirable, coal blends with even negative dilatation may produce coke with reasonable micum strength.

This observation agrees with some results on dilatometric tests reported in literature that coke strengths do not generally increase with increasing dilatation percent. According to[7], two coal blends with dilatation percent of 13% and 5% gave M10 index of 6.2% and 5.8%, respectively; and M40 index of 76.4% and 73.6% respectively. Thus, the blends with the lower dilatation produce coke with the better abrasion resistance and only a slightly lower resistance to fragmentation, M40.

Furthermore, a coal blend that gave a negative dilatation of –13% produced coke with M10 index of 5.6% as compared to 6.2% for coal blend with positive dilatation of 13%. The former coal also gave a relatively high M40 of 73%, which is only 3.6 units lower than the M40 of coke with positive 13% dilatation[7]. The dilatation percent obtained for the coal blends carbonized were observed to be far lower than 132.3% and 246.1% for Chinese Aieweh and Wugong coking coals[8]. The 220% and 275% determined respectively for a high volatile and a medium volatile American coal are very much higher than for the coals tested[9].

The observation made that the contraction and dilatation behaviour of the five coal blends carbonized do not provide a clear indication of the micum strength thus agree with results obtained in literature. From Figure 1, it was observed that the M10 decreases (i.e. improves) as the G-value increases from 0.93 to 0.97 and increases (i.e. deteriorates) as the G-value increases from 0.97 to 1.01. The lowest value of 11.40% for M10 thus occurs at G-value of 0.97 for Bellview 1 coal blend. From Figure 2, it was observed that the M40 index increases sharply as the G-value increases from 0.93 to 0.94, followed by a slight decrease at 0.97 and a sharp decrease to 64.16% at 1.01.

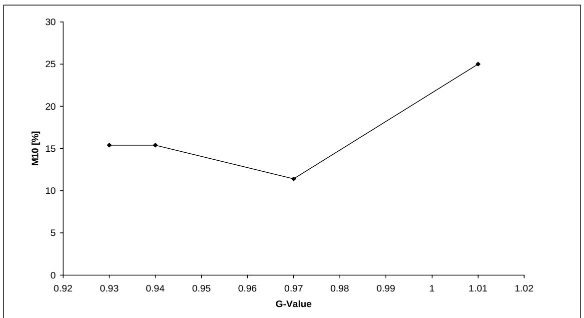

Fig. 1: M10 versus G-Value

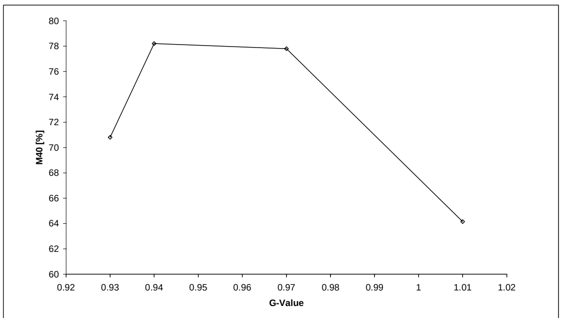

Fig. 2: G-Value versus M40

Figure 3 shows the plot of temperature ranges T_1, T_2, T_3 against the G-values. It was observed that the T_1, T_2, T_3 values decreases from 0.93 to 0.94, followed by an increase from 0.94 to 0.97. At 0.97, sharp changes in slope occur for T_1, T_2 and a slight change occurred for T_3. The least values for T_1, T_2, T_3 occur at 0.94 G-value and the highest value occur at 0.93, 0.97 and 1.01 for T_1, T_2 and T_3 curve respectively. The high value of M40 index at 0.94 compared with that at 0.93 may be due to the much lower values of T_1, T_2 and T_3 at 0.94 in comparison with 0.93. The sharp decrease in M10 and M40 strengths at 1.01 may be due to the fact that the T_2 curve has a negative slope only at 1.01 or that it is only at 1.01 that T_2 exceeds T_1 value. Thus, a coal with a high T_2 value in relation to T_1 may yield a poor grade coke. The very high increase in the M40 index for only 0.1 unit increase in G-value may be due to the much lower value of T_1, T_2, T_3 in comparison with values obtained at 0.93. At 0.97, the T_1, T_2, T_3 values are only slightly lower than at 0.93, while values at 1.01 far exceed the corresponding value at 0.93. These results suggest that coal blends with low values of Ruhr temperature ranges T_1, T_2, T_3 may produce coke of better grades than blends with much higher values of temperature ranges.

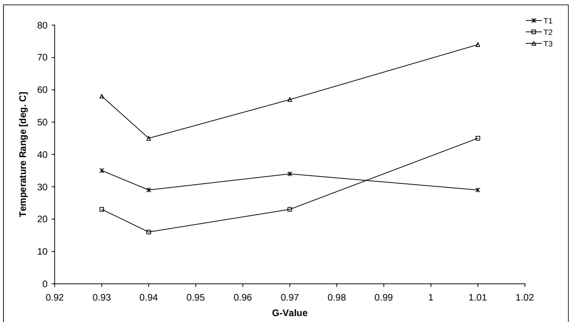

Fig. 3: Temperature versus G-Values

The micum strength determined for the coal blends carbonized agree closely with the results obtained for some German coke[10]. For a German coal blend with G-value of 0.95, the M10 and M40 obtained were 7.8% and 77.8%, respectively. The 78.2% M40 index of the Agro-Allied blend (of G-value 0.94) exceeds the M40 for the German coal by only 0.4units, while its 15.40% index is much below the 7.8% value for German coal in terms of abrasion resistance. The German coal blend with G-value of 0.97 produced coke with M10 and M40 indices of 7% and 78.1%, respectively. Thus, for the German coals, better micum strengths were obtained at higher values of G-value. The 11.40% M10 obtained for Bellview 1 at 0.97 G-value is not as good as the 7% obtained for the German coal. Similarly, the 77.80% M40 obtained for Bellview is lower than the M40 of German coal by 0.3units. For the Australian Bulli coal, the G-value of 0.99 (Audibert – Arnu) produced coke with M10 and M40 of 8% and 82%, respectively. The micum indices, though determined with different equipment are not too different from those obtained at 0.97 Ruhr G-value for Bellview coal blend. These results show that a coal blend with G-value of about 0.97 may produce high-grade coke.

It has been shown that most medium and strongly coking coals have G-values that lie in the range 0.95 to 1.15[3]. The relatively good strength obtained at 0.97 G-value of Bellview coal confirms this. However, the lower coke strength obtained for Carbon Energy coal with a higher G-value of 1.01 shows that coke strength does not generally increase with increasing G-value in the range specified. The M10 and M40 indices obtained at 0.97 G-value do not satisfy the 9% (max) M10 requirement for coke to be used at the Nigerian Ajaokuta Steel Plant. However, the M40 index of 77.80% is very close to the 78% (min.) required[11].

4. Conclusions

The Ruhr dilatometric parameters of the coal blends carbonized, particularly the G-coking capacity, and the temperature ranges, have thus shown that Bellview 1 coal blend with the G-value of 0.97 and the lowest values of temperature ranges, will produce coke with the best micum strength characteristics. The micum tests conducted confirm this prediction. Though the effects of temperature ranges on coke strength need to be investigated with more carbonization tests, the Ruhr dilatometric analysis G-coking capacity and temperature ranges have been shown to be fairly reliable parameters to predict the need for a pilot scale carbonization test.

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