Commission of the European Communities

technical coal research

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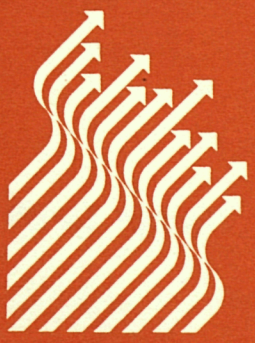

Report

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Coke quality and its prediction

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SUMMARY

The objective of the present work was to extend previous studies of the strength and structure of metallurgical coke by assessing the feasibility of using pore structural parameters and coke carbon textural compositional data, either alone or in combination, as the basis of methods of coke tensile strength prediction. The approach is feasible only if it is possible to calculate the properties of cokes from blended-coal charges from the blend composition and the corresponding properties of the cokes from individual blend components according to the additivity rule.

The cokes used were obtained by carbonizing six coals, covering the whole rank range encountered in commercial coking in the UK, and 44 two- and three-component blends based thereon in a small pilot oven. Coke tensile strengths were obtained using the diametral compression method. Textural composition data for the single-coal cokes were determined by point counting during the examination of etched surfaces in a scanning electron microscope (SEM) and during the examination of polished surfaces under incident polarised light (PLM). Pore structural parameters were measured using a Quantimet 800 image analysis system.

Initially attempts were made to relate the tensile strength of these cokes to textural composition data obtained by calculation from the blend composition and the SEM textural compositions of the six single-coal cokes. Several equations were investigated and two gave satisfactory precision. One was a purely statistical equation while the other was based on consideration of the failure of coke by a transgranular mechanism. The latter equation had the merit of identifying those coke textural components associated with high coke strength. Both equations could be used to predict the strength of coke obtainable from any combination of the six coals studied.

Comparison of measured PLM textural data for the 44 blended-coal cokes with data calculated from the blend composition and the PLM textural data for the six single-coal cokes confirmed that textural data could be considered sufficiently additive for this approach to coke strength prediction to be feasible. It was shown that equations similar in form to those used in

conjunction with SEM textural data could also be applied to PLM textural data and used in strength prediction.

Attempts to use pore structural data in this approach proved less successful, the reason being the difficulty in obtaining pore structural data with sufficient accuracy from the equipment in the form available. This also limited the attempt to use pore structural and textural data in a combined approach. Nevertheless, relationships were developed which may prove useful should more accurate pore structural information become available.

In a final approach to tensile strength prediction, the possibility of the tensile strength itself being an additive property of cokes was investigated. It proved possible to calculate the tensile strength of cokes from blended coal charges, from the blend composition and the strength of the single-coal cokes with adequate precision for predictive purposes.

The various methods of predicting the tensile strength of coke developed in this study are suitable for application in different situations. Thus, the additivity of tensile strength is the simplest approach but, provided the necessary facilities are available, the use of textural data has the advantage of permitting the quality of a coal to be assessed from only a small sample.

CONTENTS

1 INTRODUCTION

Maintaining the quality of blast-furnace coke in the face of changing patterns of coal supplies or improving it to meet more rigorous specifications requires alteration to the composition of the blend carbonized. Major changes in blend composition involve the testing of a limited number of the many possible blends available in pilot ovens[1]. Such testing programmes are expensive, hence methods of predicting the quality of coke, particularly its strength, from the results of laboratory tests on coals and/or cokes have continually been sought[2]. A method based on the petrographic examination of coal is widely used in the USA[3] but this approach has been less successful in Europe.

Efficient blast-furnace operation requires that the coke should resist size degradation as it progresses down the stack[4]. Thus current specifications for blast-furnace coke invariable include some specification for the strength of the coke. Generally coke strength is specified in terms of drum-test indices[5]. However, these indices, although widely used industrially, are based on empirical tests which are difficult to interpret on a fundamental materials science basis. Moreover, coke is a brittle material and thus, despite the mode of the imposed stress, breakage is considered to occur as a result of induced tensile forces[6]. Consequently, at least on the research level, the tensile strength of coke is gaining acceptance as an indicator of coke quality[7].

The tensile strength of coke has been related to pore structural parameters using equations derived without regard to possible variations in the properties of the coke carbon[8]. This is composed of structural units which vary in size depending on the rank of the coal carbonized[9]. These induce a characteristic texture to coke surfaces when studied by scanning electron microscopy (SEM) of etched surfaces[10] or by polarised light microscopy (PLM) of polished surfaces[9]. Both techniques can be used to obtain the proportion of the various textural components present, ie, the SEM and PLM textural composition of the coke. Coke tensile strengths have also been related to the textural composition of the cokes[11]. The major objective of the present project was to make an assessment, using coke produced in a small pilot oven, of the feasibility of using data obtained from studies

of the textural composition of the coke carbon, obtained using both the SEM and PLM techniques, and the porous structure of cokes, both individually and in combination, as the basis of a method of coke tensile strength prediction.

After considering some theoretical aspects of the approach adopted, the cokes used in this study and the methods used in their characterization are described. An assessment of the various data obtained, in relation to coke strength prediction, is then made before, finally, the application to industrial situations of the findings of this approach is considered.

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*In the interests of clarity this report contains only a digest of the extensive numerical data obtained during this study. Further details of the experimental results and the various numerical analyses carried out can be found in PhD theses submitted to the Loughborough University of Technology by Dr A Walker (1988) and Miss A Moreland (1990).

2 THEORETICAL CONSIDERATIONS

2.1 General Approach

Any coke strength prediction method involves first the establishment of a coke strength/property relationship by measuring the strength of coke obtained from oven charges of known properties. This relationship can then be used to calculate the strength of coke obtainable from any coal or blend for which the property has been evaluated. If the property considered is a coal property, then for a coal blend it can either be measured directly or, if the property is additively dependent on the blend composition, by calculation from the properties of the constituent single coals. If however, as in the present case, the property considered is a coke property, then the strength/property relationship is only useful for predictive purposes if the property can be calculated from the blend composition and the properties of the cokes from the constituent single coals; hence the attention given in this study to the question of degree of additivity.

2.2 Property Calculation Assuming Additivity

Assuming additivity of properties then the value of a property for a blended coal coke can be calculated from:

$$X = \sum_{i=1}^{n} X_i F_i C_i \qquad (1)$$

where X is the property required and X_i, F_i and C_i are the values of the property for the coke from the ith coal, the fractional content of the ith coal in the blend and a correction factor for the ith coal respectively. If a correction factor of one is used then this implies that the content, in the blended-coke, of coke from a coal is the same as the content of that coal in the blend. This is clearly not true when the coals in the blend differ in volatile matter content. The correction factor takes into account the yield of coke from the individual coals. This may either be measured or calculated from the analytical data for the coals used.

In the present study although the method based on the measured coke yields is considered the most accurate, from the point of view of strength prediction there are advantages in using the other methods if sufficient accuracy can be obtained. Hence all three methods of calculating properties of blended-coal cokes have been studied. These are referred to as the C, Y or V methods depending on whether the correction factor is one or is equal to the measured or calculated coke yield respectively. Calculated fractional yields were obtained using the relationship:

$$Z = (1 - \{[(R + M)/100])(1 - [V/100] + R/100 \qquad (2)$$

where M and R are the air-dried moisture and ash contents of the coal and V the volatile matter on a dry-ash-free basis, all values being in percent by weight.

2.3 Strength/Property Relationships

The relationships used in assessing the feasibility of this approach to coke strength prediction had either been established during previous studies funded by the European Coal and Steel Community or were developed during the course of this work.

2.3.1 Strength/Pore Structural Parameter Relationships

In studies[8] of the influence of pore structural parameters on coke tensile strength two widely applicable relationships were derived, a semi-empirical equation

$$S \times N = aW/P^2 - b \qquad (3)$$

where S is the coke tensile strength, N is the number of pores per unit area, a and b are constants, and W and P are intercept dimensions for pore walls and pores respectively, and an equation based on a materials science approach

$$S = SoFmax^{-0.5}exp[-2(Fmax/Fmin)^{0.5}.p] \qquad (4)$$

where S is the coke tensile strength, So is the strength at zero porosity, Fmax and Fmin are the maximum and minimum Feret's diameters of the larger pores and p is the fractional volume porosity. The image analysis system used in the present work did not allow the measurement of Ferets diameters so that it was not possible to use equation (4).

A further strength/pore structure relationship developed during this study took the form:

$$S \times N = a + bA \qquad (5)$$

where A is the mean area per pore and S and N have the same meaning as before.

2.3.2 Strength/Textural Composition Relationships

For relating the tensile strength and textural composition of cokes the only relationship previously used[11] was a multi-linear regression equation taking the general form:

$$S = k + \sum_{i=1}^{n} Z_i.T_i \qquad (6)$$

where Z_i is a coefficient associated with the ith textural component and T_i is its fractional content by weight. For this equation the textural composition was determined by applying a point-counting technique during the examination of etched coke surfaces in a scanning electron microscope (SEM). The relationship suffered from the disadvantage that the sign and magnitude of the coefficients gave insight into neither the breakage of coke nor the relative contribution of the different textural components to coke strength. In this work therefore further relationships were studied.

The first was a multi-linear regression equation differing from that used previously in that there is no constant:

$$S = \sum_{i=1}^{n} Z_i.T_i \qquad (7)$$

The statistical package used in fitting this equation to the data allows the coefficients Z_i to adopt positive or negative values.

Further equations were developed from consideration of a simple model of coke failing in tension by intergranular and transgranular mechanisms. Coke is assumed to be composed of a regular array of close packed, equi-sized grains, the textural components present being randomly distributed within each layer. Intergranular failure is then simply regarded as the pulling apart of two layers along interfaces between textural components. In transgranular failure, the fracture path passes through the components constituting the layer.

For intergranular failure coke strength is dependent upon the probability of contact between grains of the various types, across the interface and upon the strengths of the bonds between them. For a hypothetical coke consisting of only two textural components, A and B, the number of contacts of the type A-A, A-B and B-B in an interface is proportional to T_a^2, $2T_a.T_b$ and T_b^2, T_a and T_b being the fractional contents of the two textural components. The coke strength is then given by:

$$S = T_a^2.S_a + 2T_a.T_b.S_{ab} + T_b^2S_b \qquad (8)$$

where S_a and S_b are the strengths of cokes consisting of a single textural component failing in tension by an intergranular mechanism and S_{ab} is an intercomponent strength. Expressing equation (8) more generally for n textural components gives:

$$S = \sum_{i=1}^{n} \sum_{k=1}^{n} S_{ik}.T_i.T_k \qquad (9)$$

where S_{ik} is the intercomponent strength between the ith and kth textural components (i may equal k). This treatment is very similar to those previously used to describe the interactions between molecules in a liquid[12] and the strengths of bonds in a coke between constituents from individual blend components[13].

In transgranular failure the coke tensile strength is dependent upon the probability of occurrence of grains of the various textural types in a

layer and their strength. The strength of coke consisting of only two textural components, A and B, is then:

$$S = T_a.S_a + T_b.S_b \qquad (10)$$

where T_a and T_b are again the fractional contents of the two textural components and S_a and S_b are the tensile strengths of a coke consisting of single textural components failing in tension by a transgranular mechanism. Expressing this in general form for n components gives:

$$S = \sum_{i=1}^{n} S_i.T_i \qquad (11)$$

This equation appears identical in form to equation (7) but differs in that, unlike the Z coefficients in equation (7), the strength terms, S, are permitted only to adopt positive values.

Finally attempts were made to incorporate the reactives/inerts concept used by coal petrologists[3] into a transgranular failure mechanism. First it was assumed that for a coke consisting of a mixture of inerts and a single textural component the strength varies according to:

$$S = kI \qquad (12)$$

where I is the fractional inert content the value of which is limited to the range observed in cokes used in this study. For a multi component coke it is further assumed that the inerts are associated with the textural components in proportion to their concentration. Thus for a two-component coke the amount of inerts associated with components A and B would be $T_a.I/R$ and $T_b.I/R$ where the T terms are fractional contents of the two textural components and I and R are the fractional contents of the inerts and reactives respectively. Replacing the proportionality constant k with S_a, etc, and substituting in equation (10), the tensile strength of the blended coke failing in tension by a transgranular failure mechanism becomes:

$$S = [T_a^2.S_a + T_b^2.S_b]I/R \qquad (13)$$

which expressed more generally for n reactive components becomes:

$$S = \sum_{i=1}^{n} S_i.T_i^2.I/R \qquad (14)$$

A second equation was derived in a similar fashion except that it was assumed that the variation in strength of a coke consisting of a mixture of inerts and a single textural component was given by:

$$S = k + kI \qquad (15)$$

where I, the fraction inert constant, is again subject to the limitations noted earlier. By similar reasoning to that given above, for the case of a coke consisting of inerts and two textural components, the coke tensile strength is given by:

$$S = T_a[S_a + T_a.S_a.I/R] + T_b[S_b + T_b.S_b.I/R] \qquad (16)$$

Expressing this in a more general form gives:

$$S = \sum_{i=1}^{n} S_i(T_i + T_i^2.I/R) \qquad (17)$$

2.3.3 Strength Relationships involving both Texture and Pore Structure

The relationships used in an attempt to develop a combined pore structural/textural data approach to coke tensile strength predictions were as follows:

$$S \times N = [\sum_{i=1}^{n} S_i.T_i]W/P^2 \qquad (18)$$

$$S \times N = [\sum_{i=1}^{n} S_i.T_i]A \qquad (19)$$

Since Feret's diameters were not measured during this work, equation (4) could not be used. Thus equations (3) and (5) were combined with the strength/textural composition relationship derived from consideration of transgranular failure (equation (11)) to give equations (18) and (19).

3 EXPERIMENTAL PROCEDURES

3.1 Cokes Used

The cokes studied were produced in a small pilot oven from a series of six coals ranging in international class from 332 to 733, and 44 two- and three-component blends based on these coals. Analytical data for the coals, identified by the letters A to F, are given in Table 1. The coals were of UK origin and covered the whole range of coal rank normally encountered in blast-furnace coke production in the UK.

3.2 Carbonization Procedure

The carbonizations were carried out in a small pilot oven. In this a 600 g cylindrically-shaped charge of coal, sized 90 wt% less than 3 mm, packed to a density of 820 kg/m^3, is progressively immersed at 20 mm/h into a tubular furnace maintained at 1080°C. A plastic layer moves through the coal charge in a manner which simulates the carbonization of coal in a commercial oven. A full description of the oven and the operating procedures has been given[14].

The product from the oven is a single piece of dense strong coke, fissured internally, in sufficient quantity to permit the preparation of thirty to fifty tensile strength specimens depending on the degree of fissuring, and specimens for the assessment of the textural composition and the porous nature of the coke.

3.3 Blends Carbonized

The two- and three-component blends carbonized are listed in Table 2, the blend compositions being quoted in fractions by weight of air-dried coal. The three-component blends contained various proportions of coals A-C-F, A-E-F, A-B-E, A-C-E and A-D-E. Such blends are of two types: mixtures of high- and low-volatile coals (A-E-F and A-D-E blends) or of low-, medium- and high-volatile coals (A-C-F, A-B-E and A-C-E blends). The blends had volatile matter contents of 24, 27, 30 or 33 wt% (dafb). Both the volatile matter content and the type of blend used reflect industrial practice in

the UK but overall the range of blends carbonized exceeds that used commercially. In all 44 blends were carbonized.

3.4 Tensile Strength Determination

The tensile strengths of the cokes were determined by the diametral compression method using an Instron universal testing machine operating with a crosshead speed of 0.5 mm/min. Values quoted are mean values obtained from 30 to 50 individual 10 mm diameter by 10 mm long cylindrical test pieces.

Apparent densities of the specimens were obtained from their weights and dimensions and averaged to obtain an apparent density figure for the coke.

3.5 Textural Composition Measurement

3.5.1 SEM Procedures

To prepare etched coke surfaces for SEM examination epoxy-resin blocks 50 mm in diameter and 10 mm thick, having an upper surface containing 10 to 16 rectangular areas of uncrushed coke were prepared. These were polished by conventional techniques to a standard suitable for examination under an optical microscope. They were then etched in atomic oxygen formed from carbon dioxide in a low pressure electrodeless discharge. Adequate change in surface topography was obtained in about 20 minutes. Small specimens each containing one small rectangular surface were then cut from the large block. These were cleaned ultrasonically and gold-coated before examination in a Cambridge Instruments S604 scanning electron microscope.

The coke textural components evident in etched surfaces were classified[10] according to the scheme outlined in Table 3. This shows that textural components were classified according to their appearance into five broad categories; flat, lamellar, intermediate and granular, all derived from reactive coal components and inerts. Lamellar and intermediate components are subdivided according to the spacing of the ridges and channels which characterize their etched surface into normal and flat forms while granular

and inerts components are subdivided according to grain or particle size respectively.

The coke carbon textural composition was determined during examination of etched surfaces using a point-counting technique, 500 random points on the coke surface of eight to ten small specimens being examined and the material present being allocated to one of the textural classes described above.

3.5.2 PLM Procedures

To prepare coke samples for examination under polarized light they were first crushed gently to maximise the yield of material in the 120 - 600 μm size range. The coke grains were then embedded in epoxy-resin and moulded into a 25 mm diameter by 10 mm thick block. After curing the coke bearing surface was polished to give a scratch-free surface.

PLM textural composition data were determined using a Leitz Ortholux polarizing microscope. Crossed polars, together with a full wave retarder plate, were used to impart colour to the image which was examined using a x100 air objective and x10 eye pieces giving an overall magnification of x1000. Textural data quoted are based on the examination of 500 positions on the coke surface. At each position the textural component present was allocated to one of the 11 textural categories[15] described in Table 4. A Swift mechanical stage and electronic counter were used to position the block and to accumulate the data.

3.6 Measurement of Pore Structural Parameters

To measure pore structural parameters a Quantimet 800 computerized image analysis system was used. The TV image for analysis was obtained using an Olympus Vannox microscope fitted with x2.8 objective from a resin impregnated coke surface viewed under incident light. The surface contained 15 to 20 small rectangular coke surfaces polished to a relief- and scratch-free condition.

From each field of view the system provides the following direct measurements:

Total area	TA
Detected area (pores)	DA
Number of features (pores)	N
Total intercept length	TI
Total perimeter length	TP

These basic measurements can be used to calculate the following derived values:

Porosity	p = TA/DA
Mean area/pore	A = DA/N
Mean perimeter/pore	MP = TP/N
Mean pore intercept	I = TI/N
Mean pore size	P = DA/TI
Mean wall size	W = (TA - DA)/TI

An intercept size of a pore is its projected length in a specified direction. Thus, the intercept size of a circle is equal to its diameter. On the other hand, using the definitions given above the mean pore size of a circular pore is only 0.78 of the diameter. This latter measurement of the size of a pore was used in the present work because corresponding measurements of the wall size or interpore spacing could be obtained. With the Quantimet 800 system it is not possible to obtain intercept values for pore walls. Pore structural parameter measurements quoted in this report are mean values obtained from the examination of 100 fields of view.

4 RESULTS AND DISCUSSION

4.1 Tensile Strengths of Single-coal and Blended-coal Cokes

For the cokes obtained from the carbonization of the individual coals listed in Table 1 the measured and calculated fractional coke yields (w/w) and the coke tensile strengths are given in Table 5. The coke tensile strengths ranged from 4.42 to 6.61 MPa, such values being comparable with those of good quality blast-furnace cokes. The standard errors of the mean tensile strengths range from 0.21 to 0.29 MPa. Such values are typical of those obtained for all the cokes studied in this work. The significance of the notional strength values will become apparent later.

Experimental data for the blended coal charges are given in Table 2. Values listed include the blend composition, quoted in terms of the fractional content by weight of the air dried coals, the coke tensile strengths and the measured and calculated fractional coke yields. The two calculated coke yields (Yb and Zb) were obtained from the blend composition and the measured (Y) and calculated (Z) fractional coke yields of the single coal cokes assuming additivity of coke yield. Clearly the measured yields of the single coal cokes provide the more accurate method of estimating the yield of blended coal coke, the mean absolute difference between the measured and calculated yields being 0.007 w/w. Calculation of the coke yields from analytical data consistently underestimates the yield, the average underestimation being 0.038 w/w.

4.2 SEM Textural Composition and Tensile Strength Prediction

SEM textural composition data for the six single coal cokes are given in Table 6, the textural components being identified by their initial letters as given in Table 3. Although during counting textural components were classified into eleven categories it is now considered that the two forms of lamellar and intermediate material, normal and flat represent the same textural component. Hence in SEM textural data given in this report data for these two classes are quoted without subdivision. The table shows that cokes from high rank coals contain lamellar and intermediate components as major constituents whereas those from coals of lower rank are composed

primarily of granular components. The cokes from high rank coals also contain, as a minor constituent, the flat textural component. The six cokes contained carbonaceous inerts in amounts ranging from 15 to 30 vol%.

The errors associated with textural composition data are estimated to vary from 1 vol% at the 10 vol% level of component to 4 vol% at the 50 vol% level. Thus it is not really justifiable to quote textural data to the accuracy given in Table 6. However all the calculations described in this report, whether using SEM or PLM textural data, used fractional composition data quoted to three significant figures. So that these calculations can be repeated precisely all textural data in this report are therefore quoted to this accuracy.

To investigate the use of SEM textural data in coke tensile strength prediction the textural compositions of the blended coal cokes were calculated assuming additivity using the following relationship:

$$T_i = \frac{\sum_{k=1}^{n} T_{ik}.F_k.C_k}{\sum_{i=1}^{n}\sum_{k=1}^{n} T_{ik}.F_k.C_k} \qquad (20)$$

where T_i is the fractional content of the ith textural component in the cokes from the blended charge, T_{ik} is the fractional content of the ith textural component in the kth single coal, F_k is the fractional content of the kth coal in the blend and C_k is the correction factor for the kth coal. As described previously (Section 2.2) C is equal to one, Y or Z for methods C, Y and V respectively. The lower term in the equation is necessary to correct the textural data to a total fractional content of unity.

For the three sets of data, values of the coefficients in equation (6) were obtained by multi-linear regression analysis. The values obtained are given in Table 7 while in Table 8 the measured coke tensile strengths of the 44 blended coal cokes are compared with the strengths calculated from the three equations. It is evident from Table 7 that the coefficients in the three equations vary widely both in magnitude and sign, yet as Table 8 shows the three equations predict very similar tensile strength values

for each coke and the degree of fit between measured and calculated strengths, as indicated by the standard errors of estimation values given in Table 7, are almost identical. To illustrate the degree of fit between measured and calculated strengths implied by a standard error of 0.44 MPa, Figure 1 contains a plot of measured strengths against those calculated using equation (6) and textural data calculated using method Y.

An alternative method of comparing measured and calculated coke tensile strengths is illustrated in Figure 2. For the 44 blends studied the composition of the blends carbonized are shown at the centres of circles bearing the coke tensile strengths, the letters at the corners of the triangular diagrams indicating the coals used in the blends. Also shown on the triangular diagrams are straight dotted lines linking the composition of blends giving cokes of specified calculated strength these being obtained using equation (6) together with SEM textural data calculated according to method Y. The figures demonstrate the correspondence between the measured and calculated tensile strengths, the degree of fit being as expected on the basis of Figure 1 and a standard error of estimation of 0.45 MPa. Such diagrams are clearly of value in identifying blends giving cokes of specified calculated strength. Strengths of any specific blend can then be obtained by computation. Thus this equation can be used to predict the tensile strength of coke obtainable from any blend of the six coals examined. SEM textural composition data of the cokes considered does cover the whole range encountered in the UK coking industry but the general applicability of equation (6) has not been established.

The standard errors of estimating the tensile strengths of the blended coal cokes obtained using equations (7), (9), (11) and (17) are listed in Table 9, the three methods of calculating the SEM textural composition being used in each case. Those obtained using equation (6) are included for comparison purposes. No adequate fit could be obtained using equation (14).

It is evident from Table 9 that there is no significant difference between the standard errors of estimation obtained using the three methods of calculating the SEM textural composition. This is true for all the

relationships between tensile strength and calculated textural data, whether obtained using SEM or PLM, quoted in this report. Thus although the calculations have always been carried out using all three sets of data, in future consideration will only be given to relationships involving data calculated by method C, ie, based on the blend composition without yield correction.

From Table 9 it is evident that equation (7), the constantless multi-linear regression equation, gives the lowest standard error of estimation but, like equation (6), it suffers from the disadvantage that for all textural components the coefficients in the three equations obtained using the three sets of calculated textural data adopt values differing in sign and/or magnitude. Neither equation (6) nor (7) therefore given any indication of either the mode of coke breakage or the identity of those components contributing most strongly to coke strength.

The values of the coefficients obtained using equation (9), that derived from consideration of intergranular fracture together with the SEM textural data calculated by method C, are listed in Table 10. Using nine textural components involves 45 coefficients. The figures at the intersections of the rows and columns are the coefficients associated with the concentrations of the textural components identified by their initial letter at the top of the column and the end of the row. All values falling along the diagonal from top right to bottom left of the tables are associated with squared concentration terms and can be regarded as the strength of the bond between two identical textural components while the other values are intercomponent strengths. High strength cokes contain textural components having high intercomponent strengths. Table 10 shows that generally such strengths are associated with lamellar, intermediate and coarse and medium granular components.

The number of coefficients used in fitting equations (11) and (17) were eight and seven respectively. In the former case this was because the inert components were treated as a single textural class. For equation (17) the inert content was incorporated into the complex term associated with each textural component. The coefficients obtained are compared with those obtained using equation (7) in Table 11, standard errors of

estimation of 0.46 and 0.45 MPa being obtained. Equations (11) and (17) both ranked the contribution of components derived from reactive coal constituents to the coke tensile strength in the order intermediate > medium granular > lamellar > coarse granular > fine granular > very fine granular.

Thus, providing the textural components of the cokes from the single coal cokes are known, on the basis of the magnitude of the coefficients in equations (9), (11) and (17), ready identification of those coals capable of producing high strength cokes is possible. There is little to choose between the equations in terms of precision of prediction so being simplest in form equation (11) is considered best suited for this purpose.

4.3 PLM Textural Composition and Tensile Strength Prediction

PLM textural composition data for the six single coal cokes are listed in Table 12. The table shows that as the rank of the coal carbonized falls flow components are progressively replaced by mosaic material.

For these single coal cokes the PLM textural compositions are compared with the corresponding SEM textural data in Figure 3, all data being recalculated to an inert free basis. For this purpose the broad and striated flow categories have been considered as a single category termed flow. For the lamellar/flow, intermediate/granular flow and granular/mosaic categories the shapes of the histograms confirm the anticipated general correspondence between the textural components observed by the two techniques, the differences in textural composition between the two methods of analysis being explicable in terms of minor differences in the position of boundaries between components.

To investigate the applicability to PLM textural data of the approach to coke strength prediction successfully applied to SEM textural data PLM textural compositions for the 44 blended cokes were first computed using equation (20) from the blend composition and the measured PLM textural data for the six single cokes.

The additivity of coke textural composition data was assessed by comparing measured data for the 44 cokes with data calculated according to methods C, Y and V. This showed that departures from additivity varied in a systematic way depending on the textural component considered and the rank of the coals in the blend[16]. However the mean values of the absolute differences between measured and calculated values averaged over the 44 cokes from blended coal charges and the nine textural components present were 3.5 vol% for all three methods of textural data calculation. Thus textural composition data is considered sufficiently additive to justify the adopted approach to coke strength prediction.

Calculated PLM textural data for the blended coal cokes obtained using method C were then used to obtain the coefficients in equations (6) and (11), these equations being chosen as being representative of purely statistical and theoretically based equations respectively. Coefficients in equations (6) and (11) obtained using this data and the tensile strengths of the 44 blended cokes are compared in Table 13. The standard errors of estimating the tensile strengths from the two equations are 0.39 MPa and 0.38 MPa respectively. In both cases the standard errors are slightly smaller than corresponding values obtained using the equations and calculated SEM textural data. Clearly therefore PLM textural data can also be used in this approach to coke strength prediction. However, since for equation (6) the coefficients varied in sign amongst the various textural components this equation cannot be used to identify readily the type of coal blends giving high strength cokes.

On the other hand, the sizes of the strength terms (coefficients) obtained using calculated PLM textural data and equation (11) rank the contribution of textural components to the tensile strength of blended coal cokes in the order granular flow > coarse mosaic > medium mosaic > striated flow > broad flow > isotropic > inerts, although differences between the last four components were relatively minor. This ranking is similar to that observed for SEM textural components. Since for PLM data the standard error of estimating the coke tensile strengths using equation (11) is lower than that obtained using the multi-linear regression equation (6), equation (11) appears to be suitable both as a basis of coke strength prediction and also

as a means of identifying, from the coke textural composition data, those coals capable of producing high strength cokes.

4.4 Pore Structural Parameters and Coke Strength Prediction

Pore structural parameters for the six single coal cokes are given in Table 14. The Table shows no obvious variation of pore structural parameters with rank of coal carbonized.

To assess the applicability of this approach to coke tensile strength prediction using coke pore structural data for the 44 blended coal cokes the blend composition and the pore structural data for the single coal cokes were used to obtain calculated values for each coke from equation (1), no yield correction being used.

Comparison of the calculated data with corresponding measured values demonstrated that large deviations from additivity occurred. However the departures from additivity followed no discernable pattern, the implication being that they arose from random errors. Despite this finding attempts were still made to use pore structural data as a basis of a coke strength prediction method.

In seeking relationships between measured coke tensile strengths and calculated pore structural parameters tensile strengths were regressed against combinations of pore and wall sizes, the area per pore and the number of pores per unit area to obtain the following equations which are based on equations (3) and (5) respectively:

$$S = -2375\ W/(P^2 \times N) + 156/N \qquad (21)$$

and

$$S = -4.78 \times 10^{-3}\ A/N + 266/N \qquad (22)$$

The standard errors of estimating the coke tensile strengths from the equations were 0.86 MPa and 0.55 MPa respectively. Thus equation (22), whilst not predicting the tensile strengths of the blended coal cokes with

the precision of some of the equations used earlier, may have some application as a basis of a method of coke strength prediction.

Earlier studies had demonstrated that a correlation coefficient greater than 0.8 was obtained when equation (3) was applied to the tensile strengths and pore structural parameters of a wide range of cokes. Applying this equation to the measured strength and pore structural data for the blended coal cokes used in this study a correlation coefficient of only 0.48 was obtained. This suggests that, in its present form, the image analysis system used for this study is incapable of providing pore structural parameters with adequate precision for this approach to coke strength prediction to be realistically assessed.

4.5 Combined Texture/Pore Structure Approach

Equations (18) and (19) were fitted to the measured tensile strengths and pore structural and textural data, both calculated by method C using a method which minimised the error of estimating the coke strengths but ensured that all the coefficients were positive. The following equations were obtained:

$$S \times N = [335I + 450Mf + 125Mm + 410Mc + 535Fg + 1500Fs + 1500Fb + 190In] \times 10^2 \times W/P^2 \quad (23)$$

$$S \times N = [0.20I + 0.21Mf + 0.071Fg] \times A \quad (24)$$

These equations are associated with a standard error of estimating the coke tensile strengths of 0.50 and 0.61 MPa respectively. These values, which no doubt are influenced by the inaccuracies associated with the pore structural measurements, are considered to be too high for the equations to be useful in coke strength prediction. Nevertheless the equations illustrate the approach that could be adopted to develop a coke tensile strength prediction method based on both textural and pore structural data should accurate pore structural data become available.

4.6 Additivity of Tensile Strength and Strength Prediction

Coke textural data has been shown in this study to be a reasonably additive property of cokes. Previous studies have indicated that coke pore structural parameters are additive to a similar extent. The implication appears to be that in cokes produced from coal in the size range used in commercial coking little significant interaction occurs between particles so that there exists in the coke pockets of coke identical in textural and pore structure properties to the cokes made from the individual blend constituents. Since strength is related to both pore structural and textural data these pockets of coke should have the same strength as the single coal cokes. Hence it could be expected that the tensile strength would also be an additive property of coke.

In investigating this view as the basis of another approach to coke tensile strength prediction, relationships similar in form to relationships (9) and (11) were used, ie,

$$S = \sum_{i=1}^{n} \sum_{k=1}^{n} S_{ik}.F_i.F_k \qquad (25)$$

and

$$S = \sum_{i=1}^{n} S_i.F_i \qquad (26)$$

In these relationships S_i and S_k are the strengths of cokes made from coals i and k, S_{ik} is the strength of the bond between them and F_i and F_k are the fractional concentrations of the coals in the blends.

In fitting relationship (25) the measured tensile strengths of the six single coal cokes were used directly so that fitting the relationship involved the evaluation of the cross terms in such a way that all the values were positive. The values obtained are listed in Table 15 these being associated with a standard error of estimation of 0.36 MPa. This is the lowest value obtained in this study.

Relationship (26) was fitted to the experimental data using two methods. In the first the tensile strengths of the single coal cokes were used

directly in relationship (26). This allowed the tensile strengths of the blended coal cokes to be calculated with a standard error of estimation of 0.44 MPa. In the second method notional tensile strengths of the single coal cokes were evaluated by fitting the relationship to the blend compositions and the tensile strengths of the blended coal cokes. As Table 5 shows the notional strengths so obtained are in reasonable agreement with the measured values. using the values permitted the tensile strengths of the blended coal cokes to be calculated with a standard error of 0.39 MPa.

5 APPLICATION TO COKE STRENGTH PREDICTION

In this work it has been shown that relationships can be obtained between the tensile strengths of cokes from blended coal charges and the textural composition of the cokes calculated from the textural composition of cokes obtained from individual blend components. Also the blended coke tensile strengths can be calculated from those of the single coal cokes. All of these relationships calculate the tensile strengths with sufficient precision to be useful in predicting the strength of cokes obtainable from other blends of the six coals considered.

The strength/texture relationships developed in this work were obtained using coke textural compositions covering the range likely to be encountered in blast-furnace cokes produced in the UK. However it is recognised that the extent to which these relationships can be regarded as generally applicable to other coals carbonized under similar conditions has not been investigated. A similar limitation applies to strength prediction from the tensile strength of single coal cokes. In this sense the work can only be regarded as being preliminary in nature. For present purposes however, it is assumed that the relationships do have general applicability.

Many relationships have been used in this study and more may have been deemed useful for predictive purposes if reliable pore structural information had been available. To illustrate the application of the approach the requirements of two basic methods are considered and their use in industrial situations discussed. The simplest possible approach is adopted. Thus equations based on consideration of transgranular fracture, being simpler in form than the alternatives based on intergranular failure, are considered. No increase in the accuracy of prediction stems from making yield corrections so that calculations based on the contents of dry coals in the blends are commended.

Method I: Based on PLM textural data

Data required:

1 The tensile strengths of cokes from a number of blended coal charges.
2 Textural composition data for single coal cokes.
3 Blend compositions.

This data may be used to obtain a tensile strength/calculated textural data relationship based on equation (11). This equation also has the merit of identifying readily from the textural composition of single coal cokes those coals likely to give high strength cokes. Assuming general applicability this equation can then be used to predict the strength of coke obtainable from any blend for which the composition and textural data for the blend components is available.

Method IIa: Based on the additivity of coke tensile strengths

Data required:

1 The tensile strengths of all single coal cokes.
2 Blend compositions.

From this small amount of data the tensile strength of coke from any blended coal charge can be computed directly using equation (26).

Method IIb: Based on the additivity of coke tensile strengths

Data required:

1 The tensile strengths of a number of blended coal cokes containing all relevant single coals.
2 Blend compositions.

This is similar to Method IIa except that notional strengths of single coal cokes are obtained from tensile strengths of blended coal cokes and the

blend composition. These notional strengths may then be used to calculate the tensile strength of any other blend containing these coals.

Before considering the suitability of these methods of strength prediction in different situations some further points should be made. It is expected that the tensile strength and textural composition of coke from any coal or blend will vary depending on the carbonization conditions used. However, it is considered that the operating conditions of a 250 kg oven could be so chosen that both the tensile strength and the textural composition of coke from any blend or coal would be identical to that obtained from the same charge carbonized in a full scale oven. For small scale, eg, open boat, carbonization it is deemed only possible to simulate conditions of larger ovens only to the extent that the textural compositions of cokes carbonized on the two scales would be identical. All equations in this report relating coke strength and textural data are regarded as empirical so that although the form of the equations is expected to be applicable to other situations, it would be necessary to re-evaluate the coefficients in them for each carbonization condition.

Methods I and II for coke strength prediction have applicability in different situations. To explain this further two situations are considered. In each case it is assumed that the necessary data bases have been established.

Case A **Only a commercial oven is available and no single coal charges are carbonized.**

In this situation since no direct measurement of data from single coal charges can be made the only option available is Method IIb. On introducing a new coal it would be necessary to carbonize a number of blends of this coal with other coals of known notional coke strength and then to calculate its notional coke strength. The tensile strength of any blend containing the new coal could then be calculated using equation (26).

Case B **Commercial 250 kg and small scale ovens are available. The two larger ovens give cokes of identical tensile strength while all three ovens give cokes of identical textural composition. Single**

coal charges can be carbonized on both the 250 kg and small scales.

In this situation both methods of tensile strength prediction can be applied. However once the data bases have been established using the 250 kg oven, because coke textural data for any further coals can be obtained using the small scale carbonization, it becomes advantageous to use Method I. This situation would be particularly appropriate for the evaluation of small samples of coal, for example from bore holes.

6 CONCLUSIONS

1 The tensile strength of cokes from blended coal charges can be related to textural composition data calculated according to the additivity rule from the blend composition and the textural composition of cokes from individual blend components.

2 The textural composition may be measured by point counting during the examination of either etched coke surfaces in a scanning electron microscope or polished surfaces under polarised light.

3 Comparison of measured and calculated PLM textural compositions of cokes from blended coal charges confirms that the carbon textural composition is largely an additive property of coke.

4 The tensile strength is itself substantially an additive property of coke so that the tensile strength of blended coal cokes can be calculated from the blend composition and the tensile strength of cokes from the individual coals.

5 These two approaches to coke tensile strength prediction have applications in different situations.

6 Being based on results of small scale carbonizations these findings should be regarded as demonstrating the feasibility of the approaches, further work being necessary before they can be applied to large scale carbonizations.

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TABLES AND FIGURES

TABLE 1

Chemical analyses of coals used

Coal	International class	Air-dried		Dry-ash-free-basis			B S Swelling number	Total dilatation %
		Moisture %	Ash %	Carbon %	Hydrogen %	V M %		
A	334	0.8	7.5	91.5	4.3	19.7	8	85
B	434	0.6	4.9	90.6	4.6	20.2	8½	98
C	435	0.8	1.3	89.5	4.9	26.4	9	241
D	635	0.9	1.5	87.2	6.4	36.4	8	285
E	634	2.4	4.2	86.0	5.3	35.0	8	188
F	733	2.4	5.4	83.4	5.3	36.9	4½	73

TABLE 2

Experimental data for blended-coal carbonizations.

Blend number	Fractional blend composition						Tensile strength (MPa)	Fractional coke yields (w/w)		
	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F		Measured	Calculated (Yb)	(Zb)
1	.205	.000	.000	.000	.000	.795	4.43	.710	.709	.672
2	.103	.000	.181	.000	.000	.716	4.42	.701	.711	.672
3	.000	.000	.364	.000	.000	.636	5.27	.708	.714	.672
4	.365	.000	.000	.000	.000	.635	4.52	.726	.732	.700
5	.182	.000	.326	.000	.000	.492	5.20	.736	.737	.700
6	.000	.000	.645	.000	.000	.355	5.87	.736	.741	.699
7	.526	.000	.000	.000	.000	.474	4.65	.754	.755	.728
8	.264	.000	.469	.000	.000	.267	5.59	.770	.762	.728
9	.000	.000	.940	.000	.000	.060	5.77	.752	.769	.728
10	.688	.000	.000	.000	.000	.312	4.90	.770	.779	.756
11	.491	.000	.353	.000	.000	.156	5.69	.788	.784	.757
12	.292	.000	.708	.000	.000	.000	5.76	.786	.789	.756
13	.169	.000	.000	.000	.435	.396	5.09	.697	.717	.671
14	.129	.000	.000	.000	.871	.000	5.51	.709	.724	.670
15	.338	.000	.000	.000	.346	.316	5.41	.723	.738	.700
16	.307	.000	.000	.000	.693	.000	5.11	.736	.744	.699
17	.523	.000	.000	.000	.242	.235	5.32	.752	.762	.731
18	.484	.000	.000	.000	.516	.000	5.43	.759	.765	.727
19	.676	.000	.000	.000	.170	.154	5.69	.775	.782	.757
20	.661	.000	.000	.000	.339	.000	5.40	.784	.785	.756
21	.326	.336	.000	.000	.338	.000	4.52	.790	.786	.754
22	.000	.672	.000	.000	.328	.000	5.79	.801	.789	.752
23	.238	.243	.000	.000	.519	.000	5.31	.765	.765	.725
24	.000	.488	.000	.000	.512	.000	4.91	.769	.767	.724
25	.147	.152	.000	.000	.701	.000	5.94	.751	.744	.696
26	.000	.304	.000	.000	.696	.000	5.70	.744	.745	.696
27	.059	.060	.000	.000	.881	.000	6.10	.722	.723	.668
28	.000	.122	.000	.000	.878	.000	5.35	.731	.724	.668
29	.433	.000	.435	.000	.132	.000	5.30	.781	.788	.756
30	.293	.000	.707	.000	.000	.000	6.16	.785	.789	.757
31	.315	.000	.317	.000	.368	.000	6.06	.763	.766	.727
32	.000	.000	.928	.000	.072	.000	6.64	.771	.770	.728
33	.198	.000	.198	.000	.604	.000	6.15	.735	.745	.698
34	.000	.000	.581	.000	.419	.000	6.28	.733	.747	.698
35	.079	.000	.080	.000	.841	.000	6.29	.737	.723	.669
36	.000	.000	.233	.000	.767	.000	6.05	.710	.724	.669
37	.671	.000	.000	.162	.167	.000	5.17	.778	.788	.755
38	.684	.000	.000	.316	.000	.000	5.25	.794	.791	.755
39	.500	.000	.000	.248	.252	.000	6.27	.765	.769	.727
40	.520	.000	.000	.480	.000	.000	5.02	.769	.774	.727
41	.328	.000	.000	.334	.338	.000	6.64	.740	.750	.697
42	.355	.000	.000	.645	.000	.000	6.96	.747	.756	.697
43	.156	.000	.000	.421	.423	.000	5.69	.728	.731	.668
44	.190	.000	.000	.810	.000	.000	6.78	.737	.739	.668

TABLE 3

SEM Classification of Textural Components

Component type		Appearance of etched surface
Flat	(F)	Generally rather flat, sometimes with a fine granularity. Some regions contain scattered circular pits or short, narrow channels.
Lamellar:	(L)	Surface consists of parallel ridges and channels >5 μm long.
normal	(Ln)	Equal width ridges and channels with about 0.5 μm spacing.
flat	(Lf)	Flatter,wider ridges with narrow channels up to 3 μm apart.
Intermediate:	(It)	Intermediate in appearance between lamellar and granular forms with short (<4 μm) channels, often branched.
normal	(Itn)	Channels 0.5 - 1 μm apart.
flat	(Itf)	Flatter appearance with channels up to 3 μm apart.
Granular:		Uniform, pitted texture.
coarse	(Gc)	Pit size approximately 0.2 - 0.35 μm
medium	(Gm)	Pit size approximately 0.15 - 0.2 μm
fine	(Gv)	Pit size approximately 0.1 - 0.15 μm
very fine	(Gvf)	Pit size approximately <0.1 μm
Inerts:	(I)	Identifiable by their woody structure or, if small, by their unfused sharp edges. Particles often darker and more deeply etched than reactive matrix.
large	(Inl)	>50 μm
small	(Ins)	<50 μm

TABLE 4

PLM Classification of Textural Components

Component type		Appearance
Anthracite:		A non-porous anisotropic material which does not fuse to softening components.
plain	(A)	Single-coloured particles.
patterned	(PA)	Particles with layered structure of contrasting colour.
Flow:		Composed of elongated isochromatic areas often curved around pores.
broad	(BF)	Size >20 x 10 µm
striated	(SF)	Size >20 x 2 µm
granular	(GF)	Size >2 x 1 µm
Mosaic:		Composed of small rounded isochromatic areas.
coarse	(C)	Mean size 0.91 µm
medium	(M)	Mean size 0.63 µm
fine	(F)	Mean size 0.50 µm
Isotropic:	(I)	An optically-featureless material, often pored, which fuses to mosaic components.
Inerts:	(In)	An isotropic material identifiable by its woody structure or, if small, by unfused sharp edges.
large	(Inl)	> 50 µm
small	(Ins)	< 50 µm

TABLE 5

Yields and Tensile Strengths of Cokes from Individual Coals

Coal	Fractional coke yield, w/w		Tensile strengths, MPa		
	Measured	Calculated	Measured	Standard error	Notional
A	0.82	0.81	4.92	0.28	5.03
B	0.83	0.80	6.12	0.23	5.45
C	0.78	0.73	6.26	0.29	6.42
D	0.72	0.64	6.61	0.21	7.03
E	0.71	0.65	5.83	0.26	5.83
F	0.68	0.64	4.42	0.21	4.38

TABLE 6

SEM Textural Composition of Single Coal Cokes

Coal	Textural composition, vol%								
	Inl	Ins	F	L	It	Gc	Gm	Gf	Gvf
A	17.0	8.4	9.4	37.2	19.4	7.4	1.0	0.2	0.0
B	7.8	8.2	7.4	43.1	30.3	2.4	0.6	0.0	0.0
C	16.5	11.7	3.2	28.5	34.8	4.8	0.2	0.3	0.0
D	6.4	9.2	0.6	4.2	50.2	27.0	1.6	0.4	0.4
E	9.9	13.9	0.2	0.4	1.4	5.8	59.6	0.7	1.8
F	16.0	13.6	0.0	0.2	0.0	0.26	49.8	15.0	2.8

TABLE 7

Coefficients Obtained by Applying Equation (6) to SEM Textural Data Calculated using Methods C, Y and V

Textural component	Initial	Coefficients in MLR(29) equation for :-		
		C data	Y data	V data
Constant	K	-82.84	-10.22	-7.00
Flat	F	-737.16	136.27	-51.53
Lamellar	L	357.91	-24.97	25.21
Intermediate	It	-907.34	40.74	-12.54
Granular:				
coarse	Gc	669.24	-25.13	36.42
medium	Gm	-932.27	20.78	-7.98
fine	Gf	-2362.93	4.00	-59.21
very fine	Gvf	17933.22	-95.74	373.57
Inerts:				
large	Inl	-1034.79	17.39	-4.41
small	Ins	4053.24	30.42	98.10
Standard error of estimation:-		0.445	0.443	0.442

TABLE 8

Comparison of Measured Coke Tensile Strengths with Strengths Calculated using Equation (6)

Coke number	Coke tensile strengths, MPa.			
	Measured	Textural data calculation method		
		C	Y	V
1	4.43	4.50	4.45	4.45
2	4.42	4.82	4.79	4.79
3	5.27	5.34	5.13	5.13
4	4.52	4.61	4.59	4.60
5	5.20	5.18	5.18	5.18
6	5.87	5.73	5.75	5.75
7	4.65	4.71	4.72	4.74
8	5.59	5.53	5.54	5.54
9	5.77	6.36	6.36	6.36
10	4.90	4.82	4.85	4.86
11	5.69	5.43	5.49	5.45
12	5.76	6.06	6.04	6.04
13	5.09	5.08	5.14	5.13
14	5.51	5.83	5.82	5.82
15	5.41	5.14	5.13	5.12
16	5.11	5.66	5.65	5.64
17	5.32	5.09	5.09	5.10
18	5.43	5.50	5.49	5.49
19	5.69	5.08	5.10	5.10
20	5.40	5.33	5.34	5.34
21	4.52	5.24	5.24	5.24
22	5.79	5.13	5.14	5.14
23	5.31	5.43	5.42	5.42
24	4.91	5.36	5.34	5.34
25	5.94	5.63	5.61	5.61
26	5.70	5.58	5.56	5.56
27	6.10	5.82	5.81	5.81
28	5.35	5.80	5.79	5.79
29	5.30	5.78	5.77	5.77
30	6.16	6.05	6.04	6.03
31	6.06	5.82	5.82	5.82
32	6.64	6.44	6.44	6.44
33	6.15	5.87	5.86	5.86
34	6.28	6.26	6.26	6.27
35	6.29	5.92	5.91	5.91
36	6.05	6.07	6.08	6.09
37	5.17	5.50	5.50	5.49
38	5.28	5.65	5.65	5.64
39	6.27	5.75	5.74	5.73
40	5.02	5.98	5.97	5.96
41	6.64	6.00	6.00	5.99
42	6.96	6.31	6.30	6.30
43	5.69	6.25	6.27	6.27
44	6.78	6.64	6.66	6.68

TABLE 9

Standard Errors of Estimating the Blended Coke Tensile Strengths from SEM Textural Data

Equation	Data calculation method	Standard error of estimation, MPa
6	C	0.45
	Y	0.44
	V	0.44
7	C	0.39
	Y	0.39
	V	0.39
9	C	0.48
	Y	0.48
	V	0.48
11	C	0.46
	Y	0.46
	V	0.46
17	C	0.45
	Y	0.45
	V	0.45

TABLE 10

Coefficients Obtained by Applying Equation (9) to SEM Textural Data Calculated using Method C

	Inl	Ins	F	L	It	Gc	Gm	Gf	Gvf
Gvf	3.0	4.5	3.0	2.5	2.5	2.5	2.5	2.5	3.0
Gf	3.0	4.5	2.5	5.5	8.7	5.5	5.0	3.5	
Gm	3.0	4.5	2.5	7.0	9.0	9.3	8.1		
Gc	3.0	4.5	2.5	7.0	9.5	5.0			
I	3.0	4.5	2.5	12.4	8.2				
L	3.0	4.5	2.5	3.5					
F	3.0	4.5	3.0						
Ins	0	0							
Inl	0								

TABLE 11

Coefficients in Equations (7), (11) and (17) Obtained using SEM Textural Data Calculated using Method C

Textural component	Initial	Coefficients in equations:- (7)	(11)	(17)
Flat	F	1.74	0.8	0.7
Lamellar	L	*	5.5	5.9
Intermediate	It	11.08	11.0	10.8
Granular:				
coarse	Gc	-0.19	4.5	3.6
medium	Gm	7.62	7.7	7.8
fine	Gf	-35.74	2.2	0.9
very fine	Gvf	118.8	1.0	0.9
Inerts:	I		1.4	
large	Inl	16.19		
small	Ins	*		

*Indicates that data was not used by statistics software in calculating coefficients

TABLE 12

Measured PLM Textural Composition of Cokes Prepared from Individual Coals

Coal	PLM Textural Composition (vol%) of Cokes								
	Inl	Ins	Fb	Fs	Fg	Mc	Mn	Mf	I
A	16.2	6.2	14.0	31.6	27.4	2.9	0.8	0.4	0.5
B	14.0	5.7	26.6	19.5	23.2	3.6	4.9	0.8	1.7
C	13.5	8.7	0.9	20.7	45.6	9.2	0.5	0.3	0.6
D	6.4	4.0	0.5	2.1	24.8	48.6	11.6	0.8	1.2
E	8.5	5.6	0.5	1.6	4.5	7.0	53.2	14.2	4.9
F	8.3	12.7	0	0	1.3	1.9	33.9	32.9	9.0

TABLE 13

Coefficients Obtained by Applying Equations (6) and (11) to PLM Textural Data Calculated According to Method C

Textural component	Initial	Coefficient in equation (6)	Coefficient in equation (11)
Constant	K	-48.9	
Flow:			
broad	Fb	119.0	1.6
striated	Fs	53.7	5.0
granular	Fg	10.3	9.6
Mosaic:			
coarse	Mc	54.8	7.1
medium	Mm	76.8	8.0
fine	Mf	-174.1	3.0
Isotropic	I	347.6	1.9
Inerts:	In		1.2
large	Inl	-125.6	
small	Ins	564.6	
Standard error of estimation		0.39 MPa	0.38 MPa

TABLE 14

Mean Pore Structural Parameters of Single Coal Cokes

Coal	Internat Class	Mean pore structural parameters						
		Porosity (vol%)	Area/ pore (μm^2)	Perimeter/ pore (μm)	Pore intercept (μm)	Pore size (μm)	Wall size (μm)	Pores /mm^2
A	334	62.0	25517	924	294	88	53	25.0
B	434	59.4	28886	682	215	132	89	22.3
C	435	59.7	20647	486	196	135	91	30.0
D	635	65.5	35757	719	227	158	83	18.7
E	634	61.6	27359	779	246	108	67	22.8
F	733	59.5	14749	373	116	127	86	41.4

TABLE 15

Intercomponent Strengths Obtained using Equation (25)

Component cokes from coals:		Intercomponent strength, MPa
A	B	3.80
A	C	5.70
A	D	6.13
A	E	5.73
A	F	4.81
B	D	4.80
B	E	4.74
C	E	6.68
C	F	5.54
D	E	6.47
D	F	5.48

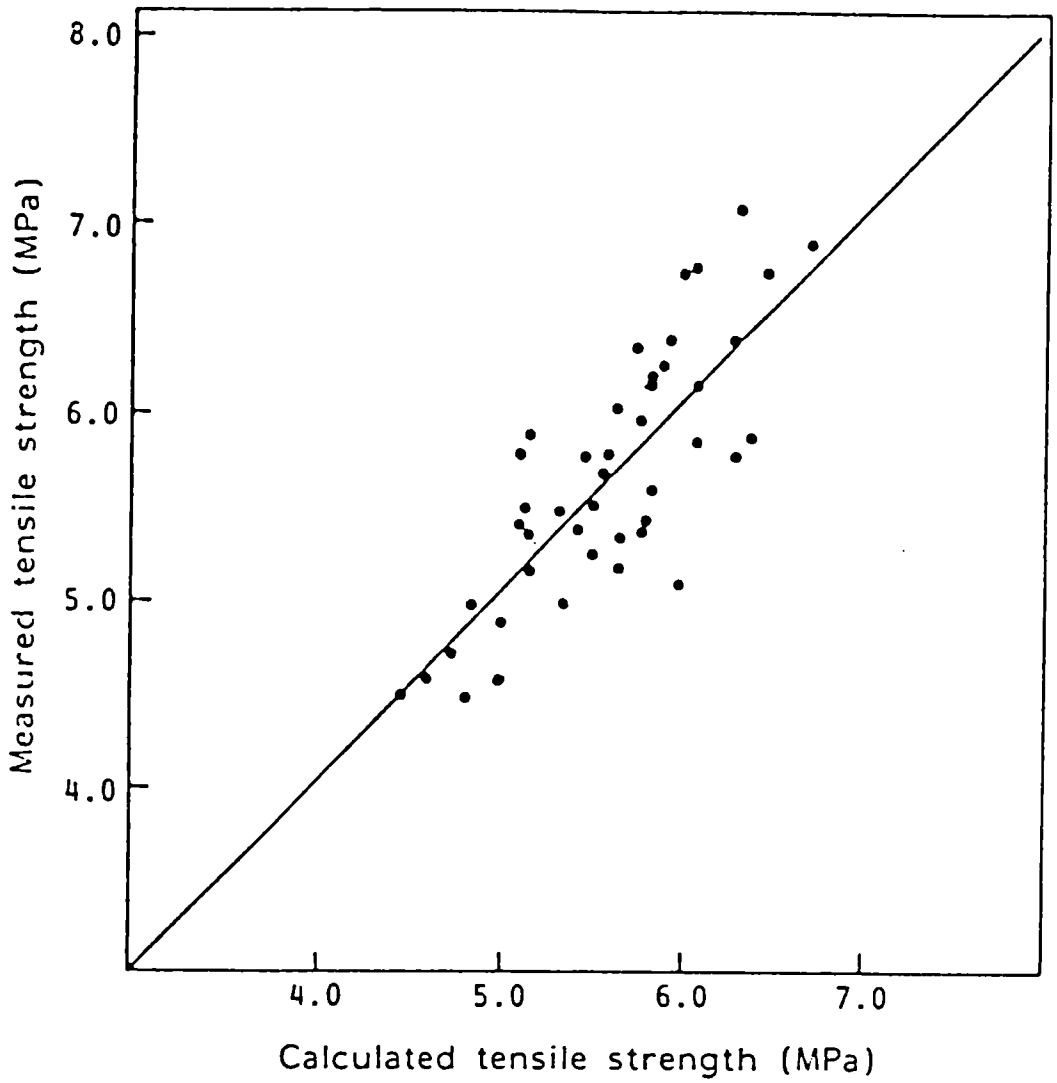

Figure 1 Comparison of measured tensile strengths with those calculated using equation (6) and SEM textural data calculated using Method Y.

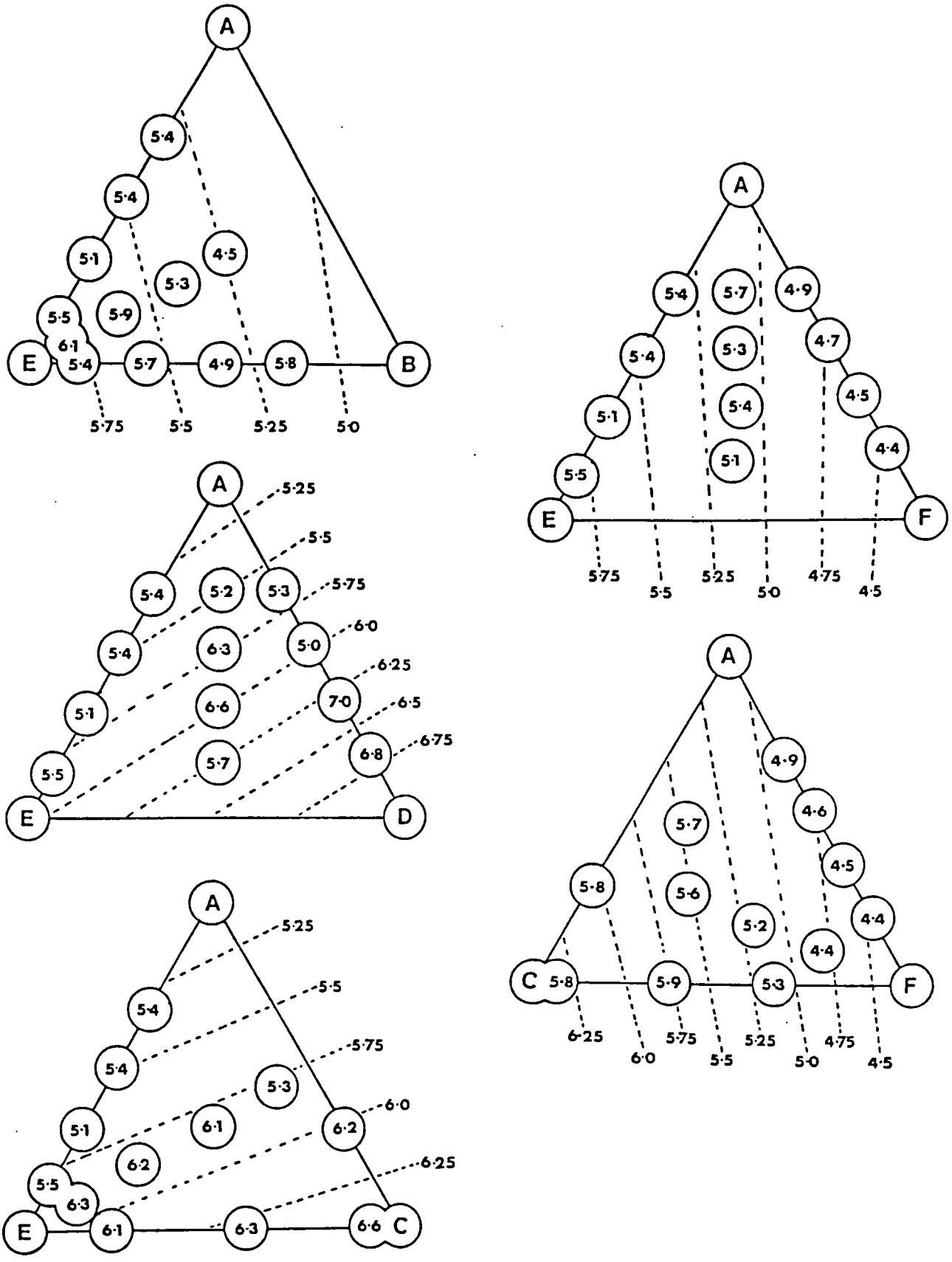

Figure 2 Compositions of blends carbonized lie at centres of circles bearing coke tensile strengths. Dotted lines are iso-strength lines.

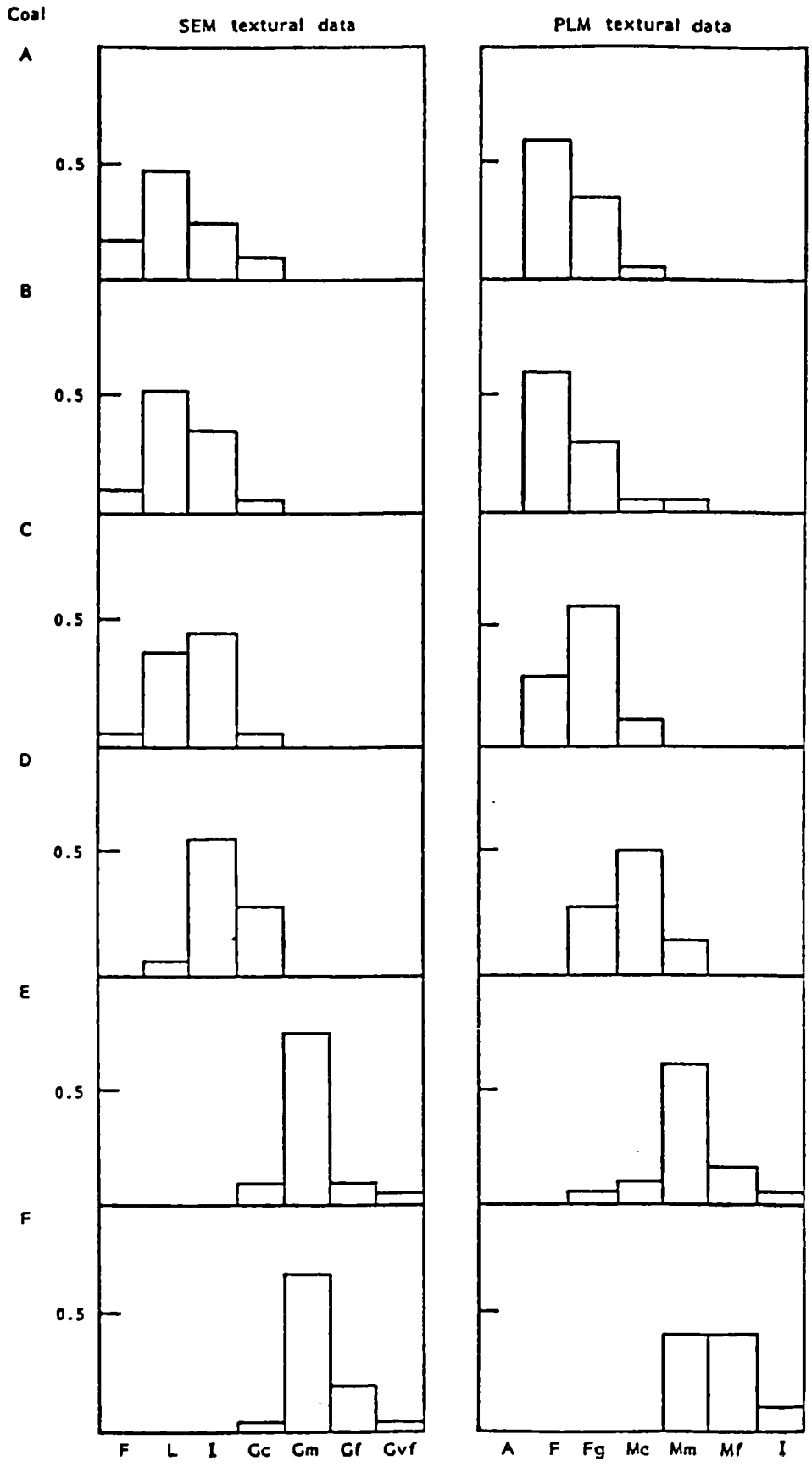

Figure 3 Comparison of SEM and PLM textural compositions of single coal cokes.

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