THE PREDICTION OF THE QUALITY OF COKE BY THE USE OF V^r-G DIAGRAMS

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All properties of coal are more or less related to the coalification metamorphism. However, caking properties (plasticity) also affect the coke strength. Upon heating, coal undergoes chemical changes, giving rise to the evolution of gas and condensible vapors and leaving behind a solid residue consisting almost entirely of carbon. In the temperature range 350-500° C, depending on the rank of the coal, coking coal softens, becomes plastic, and coalesces into a coherent mass which swells and then forms a solid porous structure. In this series of transformation, two important temperature zones can be distinguished. The first is that in which the coal is plastic and the second is that at higher temperature in which the resolidified material contracts. A strong contraction and resolidification, which is likely to occur with coals of high volatility and plasticity, produces many fissures in the coke, leading to lower mechanical strength. Coke strength is, therefore, closely associated with agglomeration of particles, pore size and its distribution, strength of cell wall and development of fissures. It is assumed that the coke strength may be expressed statistically as a function of these two parameters.

Many methods to predict the strength of coke have been proposed. These methods are as follows:

(1) $\overline{R^\circ}_{max}$--Log α_{max} diagrams put forward by Miyazu.[1] Here, $\overline{R^\circ}_{max}$ is the mean maximum percent reflectance of vitrinite. α_{max} is the maximum percent fluidity measured by the Gieseler plastometer.

(2) V^r--b diagrams, put forward by Simonis.[2] Here, V^r is the percent by weight volatile matter on a dry, ash-free basis, and b is the total dilatation of the coal, measured by the Audibert-Arnu dilatometer.

(3) X--Y diagrams have been used in the Soviet Union.[3] Here, X is the final drop of the expansion-pressure curve which is function of V. Y is the thickness of the plastic layer of the Sapozhnikov test, which reflects the quantity of the plastic mass.

(4) S.I.--C.B.I. diagrams were used by Shapiro[4]. S.I. and C.B.I. are the abbreviations of Strength Index and Composition Balance Index. These values are obtained from petrographic analysis.

(5) V^r--G diagrams has been put forward by the Central Coal Mine Research Institute[5]. G is the caking index of coal, which is the modification of Roga Index.[6]

Experimental

More than 400 samples of bituminous coals were selected from the main coal fields of China. Among these, 177 samples of 2 tons each were taken from bituminous coal mines and seams representing different ages of coal formation and periods of metamorphism. Examinations were made according to the requirements for coking tests on a semi-industrial scale using a washer, a 200kg coke oven, different sizes of automatic screens, a micum drum, etc. The raw coal was cleaned by a jig washer, 85% of the coal charged into the coke oven was less than 3mm in size and had a moisture content of 10%. The test coke-oven was constructed of aluminum and magnesium blocks. The carbonizing chamber has a width of 450mm. The coke strength was determined by the ISO/R 556-1967(E) test. The M40 index, crushing strength of coke; the M10 index, abrasive strength of coke; the F10 index, the yield of coke powder of less than 10mm, and the Q60 index, block coke of larger than 60mm after the drop-shatter test, were determined.

The proximate analysis, ultimate analysis, petrographic analysis and tests of caking and coking properties were determined. Most of the test methods adopted are similar in principle to the corresponding methods specified in the International Standards issued by ISO.

Results

Statistical analysis on the coalification metamorphism-- Volatile matter and mean maximum reflectance of coal have been most commonly used as parameters to describe the coalification metamorphism.[7,8] There is a good correlation between these two indices as shown in Table 1. Although the volatile matter index is made on whole coal and reflectance solely on vitrinite, which is generally about 50-80% in coking coal, there is still a good correlation. Ultimate analysis, such as carbon content, hydrogen content, and atomic H/C and O/C ratios have also been used (Table 2).

Table 1. Correlation Between V^r and $\overline{R^o}$ max

Source	Regression Equation	Correlation Coefficient
U.S.A.	$\overline{R^o}$ max $= 2.476 - 0.0402 x V^r$	-0.944
Canada & Australia	$\overline{R^o}$ max $= 2.519 - 0.0465 x V^r$	-0.884
China	$\overline{R^o}$ max $= 2.12 - 0.0357 x V^r$	-0.917

Table 2. Correlation between C^r, H^r, O^r and V^r (Samples 390)

Regression Equation	Correlation Coefficient
$V^r = 247.76 - 2.52 x C^r$	-0.86
$V^r = 15.28 x H^r - 49.57$	0.90
$V^r = 10.7 + 2.64 x O^r$	0.79
$C^r = 108.28 - 4.15 x H^r$	-0.72
$C^r = 94.32 - 1.11 x O^r$	-0.98

Statistical analysis of the caking properties--Although caking properties of coal are not always proportional to the coking power, they plan an essential role during carbonization in determining the strength of the coke.[9] Each test index has its own features. Most of them, such as Roga index (RI), Caking index (G), Gray-King index (GK), Crucible Swelling index Number (CSN), etc., reflect the overall result of the process which converts coal from the solid state into the plastic state and then resolidifies it into a solid coherent body with a porous structure. Some of them reflect the temperature range of the plastic state while others reflect the fluidity of the plastic mass. The correlation of these indices, therefore, is sometimes good and sometimes poor. The correlation coefficients between indices of cohesiveness of coal are summarized in Table 3.

Table 3. Correlation Coefficients between Indices of Cohesiveness of Coal

	G	R.I.	C.S.N.	G.K.	Y	b	Log α max
G	1.00	0.98	0.78	0.94	0.83	0.73	0.86
R.I.	0.98	1.00	0.77	0.91	0.80	0.69	0.87
C.S.N.	0.78	0.77	1.00	0.80	0.63	0.58	0.37
G.K.	0.94	0.91	0.80	1.00	0.86	0.83	0.88
Y	0.83	0.80	0.63	0.86	1.00	0.92	0.66
b	0.73	0.70	0.58	0.83	0.92	1.00	0.76
Log αmax	0.86	0.87	0.37	0.88	0.66	0.76	1.00

Relationship between components and properties of coal and coke strength--Among the 177 samples used in the coke-oven tests, 29 samples could not go through the tumbler test. After deducting the samples of charges containing >15% ash, there remained 134 coal samples. Organic components, coalification metamorphism and caking properties are internal variables characteristic of the coal used. In addition, the coke produced also depends on external variables such as the particle size of coal, the bulk density of the charge, the heating rate, the coking temperature, the coking time and the structure of the coke oven. In the present study, these external variables are constant. It was, therefore, possible to use a few parameters referring to the internal variable of coal coking to reflect the relation between the property of coal and coke strength.

Trend surface analysis can be used to solve this problem. It has been carried out for 134 coal samples. The results are listed in Table 4. The F-test demonstrated the following:

(1) The second order equation, square trend-surface equation, is distinctly better than the linear equation, and

(2) The cubic equation does not have a significant difference as compared with the second order equation.

Table 4. Goodness of Fit for V^r--G on Coke Qualities

Fitting	Indices of Coke Qualities				
Trend Equation	M40	M10	Q60	Q40	F10
Liner	0.53	0.68	0.36	0.62	0.56
Square	0.69	0.82	0.50	0.80	0.77
Cubic	0.70	0.82	0.53	0.85	0.77

Therefore, the second order equation is used to indicate the trend surface. From Figures 1 and 2, the following information may be obtained:

(A) When a coal has a volatile matter (daf) of less than 30%, the coke strength is mainly controlled by the cohesiveness.

(B) When a coal has a volatile matter (daf) of more than 30%, the coke strength is controlled by both the cohesiveness and the degree of metamorphism of coal.

(C) As the volatile matter (daf) increase, the strength is more affected by the degree of metamorphism of coal.

(D) The effect of the degree of coal metamorphism is greater on the M40 index than on the M10 index. The effect of the cohesiveness is larger on M10 than on M40.

It may be seen from Figures 3 and 4, that the percentage of lump coke is mainly affected by the degree of coal metamorphism. As V^r increases, the percentage of lump coke decreases.

It may be seen from Figure 5 that the percentage of coke breeze is mainly affected by the cohesiveness of the coal. The higher the V^r, the more it is affected by the cohesiveness of coal.

If other indices reflecting the degree of coal metamorphism and the cohesiveness were used, similar relations would be obtained (Table 5). The combinations of V^r and other indices reflecting cohesiveness usually did not show any difference in goodness of fit for the M40 index. As for the M10 index, the combination of V^r--G is distinctly better than V^r--Y or V^r--Log αmax, or C.S.N. Thus, it is evident that

(1) Caking index G, which we have improved, is better than other indices reflecting cohesiveness of coal.

(2) Index V is better than $\overline{R^o}_{max}$. The former is based on whole coal and the latter is based on vitrinite in coal only.

Table 5. Comparison of Goodness of Fit when Fitting with Different Indices

Combination of Different Indices	Coke Strength M40 Square	M40 Cubic	M10 Square	M10 Cubic
V^r vis. G	0.69	0.70	0.82	0.82
V^r vis. R. I.	0.69	0.70	0.78	0.81
V^r vis. Log α_{max}	0.67	0.69	0.66	0.72
V^r vis. Y	0.66	0.69	0.55	0.70
V^r vis. C.S.N.	0.68	0.72	0.56	0.59
V^r vis. b	0.63	0.67	0.44	0.62
$\overline{R^o}_{max}$-Log α_{max}	0.59	0.60	0.66	0.70
$\overline{R^o}_{max}$-$(\Sigma d)_{2/3}$*	0.57	0.62	0.33	0.39

* $(\Sigma d)_{2/3}$, vol. % of 2/3 semi-vitranite in coal plus fusinite and semi-fusinite, then plus mineral impurities in coal.

Taking advantage of these results, we can estimate the strength of coke using the diagram of V^r--G. We must point out that these results have been obtained from a semi-industrial scale oven and are different from the results in a conventional coke oven. In general, the coke strength is slightly lower for the smaller oven, but it is not important in selecting the blending ratios of coals.

If the value of blending coals in the V^r--G diagram does not fall in the optimum area, we can add some coals to the blending coals to move the position in the V^r--G diagram into optimum area. In addition, we may use further treatment to enhance the ability to make better coke or to improve the economics of manufacturing coke. The methods of further treatment are shown in Figure 6. We can, for example, use preheating to improve the caking ability of these blending coals, which are low in caking ability and have a position in the V^r--G diagram low on the optimum area. The optimum area for blending has V^r values from 28% to 32% and G values from 60 to 75.

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FIGURES:

1. Forecasting the M40 with the square trend surface.
2. Forecasting the M10 with the square trend surface.
3. Forecasting the Q60 with the square trend surface.
4. Forecasting the Q40 with the square trend surface.
5. Forecasting the F10 with the square trend surface.
6. Some methods of further treatment to improve the coke strength using V^r-G diagram.

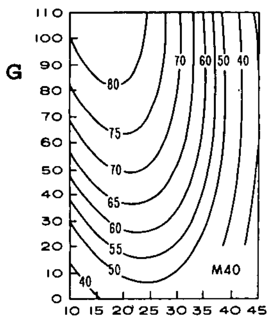

Figure 1

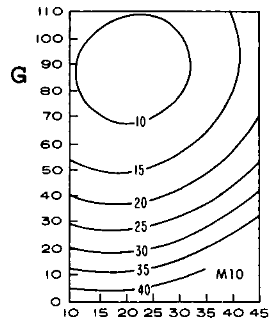

Figure 2

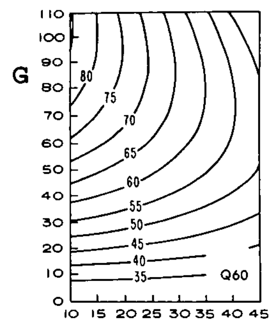

Figure 3

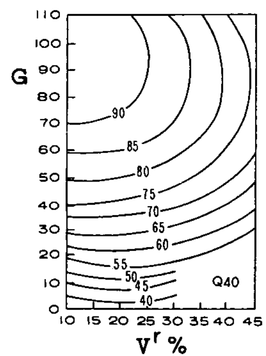

Figure 4

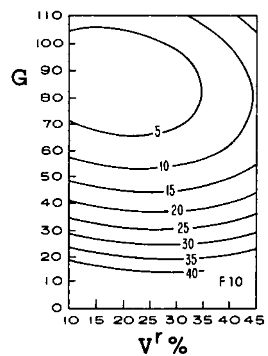

Figure 5

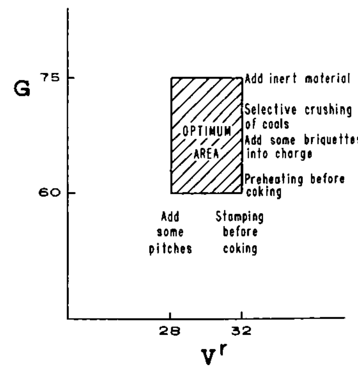

Figure 6