

SELECTION AND EVALUATION OF BLENDS FOR COKEMAKING

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1. Introduction

For the manufacture of good quality metallurgical coke, it is necessary in the first place to select coals that have the suitable properties. For this reason, the procedure for correctly evaluating the properties of coking coals naturally has the most important role among the cokemaking techniques. Particularly in Japan, there are few resources of good quality coking coals, hence it has been an important mission for those concerned to select coals for importing from abroad that are suitable for coke making and use them effectively. It is desired that coals for the making of metallurgical coke be as low in ash and sulphur contents as possible, but it is even more important for them to have good coking properties necessary for the forming of lump coke of excellent strength. As for the strength of coke, the drum strength measured at room temperature was taken as a target formerly, but recently as the behavior of coke in the blast furnace comes to light, the strength of coke after its reaction with CO_2 , has become a necessary item.

The coking properties of coals aimed at coke strength evaluation have been known from old to depend on two parameters, coal rank and caking property. The content of volatile matter and the reflectance of vitrinite have been used as characteristics of coal rank, and the caking index, maximum fluidity by Gieseler plastomer, coefficient of total expansion by dilatometer, etc., used as characteristics of caking property. By proper combination of these characteristics, coals have been classified and evaluated with several methods. More recently, coal petrographic analysis has been introduced, and Nippon Steel has established a corporate-level standard procedure by combining it with the method using the strength index and composition balance index proposed by N. Schapiro and others. Coal evaluation through the medium of coke strength after reaction with CO_2 also adopts the concept of coal petrographic analysis.

The method of coal evaluation applying coal petrographic analysis has much of an empirical aspect, and this point needs to be taken into consideration in applying this method. The present procedure of coal evaluation still leaves a

number of points to be improved, and is likely to develop further in the coming years. The present report discusses the properties and classification of coking coals used at Nippon Steel and the procedure of coal quality evaluation centered on the estimation of coke strength and post-reaction strength.

2. Coking coal properties and classifications

The coals actually used now at Nippon Steel, as shown by an example of 1986, represent 7 countries and over 90 brands, and vary very widely in their properties. The principal sources of coking coals imported from abroad are the USA, Australia and Canada, these three countries combined accounting for over 70 percent of the total tonnage used in Japan. To continue effective use of this great variety of coals, a method of classification is indispensable that would allow the features of these coals to be distinguished definitely. Nippon Steel uses a method of classification based on two indices, SI and CBI, as determined from the reflectance of vitrinite and maceral composition measured by the use of an automatic petrographic analyzer (Fig.1). To supplement this method of petrographic analysis, each incoming shipment of coals is checked for caking properties by button number, Gieseler plastometer, and dilatometer, in addition to proximate analysis and total sulphur analysis. Moreover, a carbonization test by small electrically heated coke oven (80 Kg/oh) is conducted to measure the drum index and strength after CO₂ reaction of the coke formed. The caking properties of non or slightly caking coals that have come into increasing use with the development of coal charge preparation technique are difficult to determine with the method of measurement applied to ordinary coking coals. These coking coals, therefore, are measured also for caking index by a method devised by Nippon Steel. Since the coals used by Nippon Steel are thus diversified with their producing districts, brands, etc., covering an extensive range, the practice with the basically employed method by coal petrographic analysis is to check them with the characteristics measured by the various methods mentioned above.

(Fig. 1)

On the other hand, the Coke Division of the Japan Iron and Steel Institute, in order to cope with recent trends such as the expanded and diversified range of coking coals, the diffusion of coal charge preparation technique, and the importance attached to coke strength after reaction, has studied method of classification for coking coals and proposed a new unified method of classification (Fig.2). This method consists of a major classification breaking coking coals down into 11 groups by the reflectance (Ro) of vitrinite and the maximum fluidity MF (log DDPM) by Gieseler plastometer and further a minor classification by classification codes adding total inert content thereto (Table 1). In the future, this method will be adopted increasingly for the classification of unblended coals.

(Fig. 2)

Table I

3. Coking coal quality evaluation procedure

3.1. Basic ideas

The purpose in evaluating the quality of coking coals can be said to determine their proportions such that coke having the quality necessary for stable blast furnace operation can be produced most economically. Nippon Steel purchases over 90 brands of coals, distributes them to 8 coke plants, and at the same time manufactures coke from coal charges in which 13 to 15 brands are blended. In order to purchase, distribute and blend coking coals most suitably, premising the required quantity and desired quality of coke, it is necessary to predict coke quality from the properties of individual unblended coals, and this constitutes the basis of coal quality evaluation procedure. The coke components, such as ash and

total sulphur, can be estimated by additive calculation from the values of unblended coals and there is no particular problem in this connection. The objects of coke quality prediction are drum strength (DI_{15}^{150}) and strength after CO₂ reaction (CSR), and coal petrographic analysis is applied to estimate these. The main reasons for adopting the method based on coal petrographic analysis include the fact that it is suited for determining the properties of unblended coals, the fact that the development of automatic petrographic analysis procedure has made measurement speedier, and the fact that the evaluation by coal petrographic analysis has been easily understandable by the coal suppliers because of the diffusion of this practice.

The present system of coke quality estimation does not take into account the effect of coal charge conditions (particle size, moisture, bulk density) and the effect of coke oven carbonization conditions. This is because it is difficult to quantify these effects generally since the coke oven size is different among the eight coke plants and since there are differences in coke oven operating conditions, preparation technique, and coke processing technique such as CDQ. Therefore, the procedure for coke quality estimation is to determine the dependence of coke quality on the properties of coking coals under standard conditions, and the effect of manufacturing conditions is to be evaluated at the individual coke plants, taking local conditions into consideration.

3.2. Procedure for estimation of the strength (D_{15}^{150}) of coke

The estimation of coke strength by coal petrographic analysis is basically a modified version of the method developed by N. Schapiro and others. The main points of modification are the indication of coke strength by JIS drum index and the use of values automatically measured by computer for reflectance and maceral analysis. In the maceral analysis by automatic measurement, the result is indicated as the proportions of three maceral groups, vitrinite, exinite and inertinite, hence the proportion of reactive components is the sum of vitrinite and

exinite, and the proportion of inert components is inertinite itself. The petrographic analysis of unblended coals is used to compute the strength index (SI) and composition balance index (CBI) of blended coals by additive calculation according to the proportions of individual coals used, and a previously prepared diagram of the relation of coke strength to SI and CBI is used to predict the strength of coke to be formed from the blended coals. This standard SI-CBI diagram (Fig.3) for determining coke strength is prepared on the basis of the results of a cokemaking test with the properties of blended coals widely varied using an actual coke oven. The standard manufacturing conditions to produce the coke strength predicted by this SI-CBI diagram are approximately as follows:

| | |
|---------------------------|------------------------|
| Blended coal size | : -3 mm, 86% |
| Blended coal bulk density | : 0.7 t/m ³ |
| Flue temperature | : 1,230°C |
| Soaking time | : 3 hrs |
| Coking chamber width | : 450 mm |

(Fig. 3)

There has been found a good correspondence, such as shown in Fig.4, between the actually measured value and estimated value of coke strength (DI_{15}^{150}) determined by analyzing the test results.

(Fig. 4)

Recently, meanwhile, with the increasing use of Australian or Canadian coals which are high in inert content, a difference occurs sometimes between the coke strength estimated by the diagram of Fig.3 and the measured strength of coke manufactured. When blended coals decline in fluidity as a result of their increased inert content, actual coke strength tends to become lower than the estimated value

(Fig.5). This indicates that since the SI-CBI diagram used as a basis for coke strength estimation is empirically prepared, it needs to be modified in case the properties of blended coals change significantly due to the use of different unblended coals from those when it was prepared.

(Fig. 5)

To modify this diagram so that it can successfully suit the existing properties of blended coals, coke manufacturing test was conducted using 54 coal charges obtained by blending 16 brands which were selected mainly from among Canadian and Australian coals. As a result, the following two modifications were made. One is the correction of CBI of unblended coals by the following formula:

$$\text{Corrected CBI} = -0.801 \log \text{MF} + 3.812$$

This means the correction for the difference between the calculated CBI and the actual CBI which occurs as one-third of semi-inert components of Canadian and Australian coals is assumed to be vitrinite in the same manner as is done with American coals. Moreover, it includes the correction for the low detecting capacity of petrographic analysis method for weathered coals. The other modification is the correction to the diagram, i.e., the review of the isostrength curves in the low fluidity range (high CBI). Owing to these modifications, the SI-CBI diagram can almost successfully suit the existing properties of blended coals, including Australian and Canadian coals.

3.3. procedure for estimation of coke strength after CO₂ reaction

Two major methods are used for estimation of CSR. One is based on the assumption that the CSR can be expressed by coke reactivity with CO₂ (CRI) and strength (DI_{15}^{150}) (Fig.6). Namely, assuming that coke reactivity (CRI) can be estimated by additive calculation from the measured values of coke made from unblended coals, the DI_{15}^{150} of coke from blended coal is calculated by the method

described above and the CRI of coke from blended coal is calculated by additive calculation from the measured value of coke from unblended coals. Using the DI_{15}^{150} and CRI of coke made from blended coal as calculated above, the CSR of coke made from blended coal is obtained from Fig.6. The other method is to estimate the CSR of coke made from blended coal by reference to the reflectance (R_o) of vitrinite, the inert content of coal and the alkali content of ash as parameters based on the fact that the optical isotropic texture of coke (Fig.7) bearing a close relation with coal rank selectively reacts with CO_2 .

(Fig. 6)

(Fig. 7)

$$CSR = f(R_o, I, B)$$

where R : reflectance of vitrinite

I : inert content

B : alkali content of ash

An example of the results of estimation by this procedure is shown in Fig.8.

It has been found that the CSR can be estimated with a high accuracy by calculating, in the first place, the CRI based on the formula shown above and then estimating the CSR by the former method using the CRI thus calculated.

(Fig. 8)

When blended coals decline in fluidity, however, the values calculated by the methods described above tend to become lower than the estimated values. though the reasons for such difference have not been fully elucidated, one of the most probable reasons is as described below. Namely, lump coke made from blended coal with high fluidity is uniform in matrix strength and reactivity but such

uniformity is decreased as the fluidity declines. As a result, the properties of whole lump coke are dominated by the fragile portion which is low in strength and high in reactivity, thus leading to lower DI_{15}^{150} and CSR than those of lump coke of uniform strength and reactivity.

3.4. Effect of cokemaking conditions

Among the manufacturing conditions that affect coke quality, the preparation of coal charges is of particular importance. Since coke quality improvement by preparation varies, as shown in Fig.9, with the method of preparation and the level of coke quality, Nippon Steel's practice is to make corrections with consideration for this point in estimating the quality of coke and determining the coal blend proportions.

(Fig. 9)

Coke quality improvement by coal preparation is through due mainly the improvement of bulk density and the pulverization of coal particles as shown in Fig.10. The improvement of bulk density has a great effect on the pores in the formed coke, resulting in the improvement of coke strength. Originally, the coke texture can be changed by changing the heating rate. It is, however, difficult to significantly change the coke texture by changing the heating rate within the temperature range being now employed in the coking chambers. In other words, changes in heating rate do not contribute directly to the improvement of CSR. Coal pulverization improves the strength of coke matrix by uniformly dispersing coal components. Rise in coking temperature has an effect on the reactivity of coke matrix, resulting in higher CSR.

(Fig. 10)

(Fig. 11)

4. Conclusion

The paper has described that the determination of coal characteristics and the blending method suitable for manufacture of good quality coke are of particular importance in Japan. Furthermore, the paper has outlined the procedure for measurement of coal properties and the procedure for estimation of the strength (DI_{15}^{150}) and the strength post reaction with CO_2 (CSR) which are now in use at Nippon Steel. These procedures are for estimation under the constant coking conditions. Since Nippon Steel has eight coke plants, however, a standard estimation procedure is required. As the oven volume, coking conditions, method of coal preparation, etc. are different among the eight coke plants, it is necessary to establish the methods for estimation of DI_{15}^{150} and CSR with consideration for such differences. These points will be discussed at the panel for carbonization

References

- 1) M.Sakawa, Y.Sakurai, and Y.Hara: Fuel, 61 (1982) 717.
- 2) M.Sakawa, Y.Sakurai, Y.Shimomura, Y.Hara, M.Ushikubo, S.Uwano and S.Suzuki: Fuel Association Journal, 63 (1984) 397.
- 3) K.Kojima, Y.Sakurai, T.Sugai and M.Motegi: Fuel Association Journal, 53 (1974) 1073.

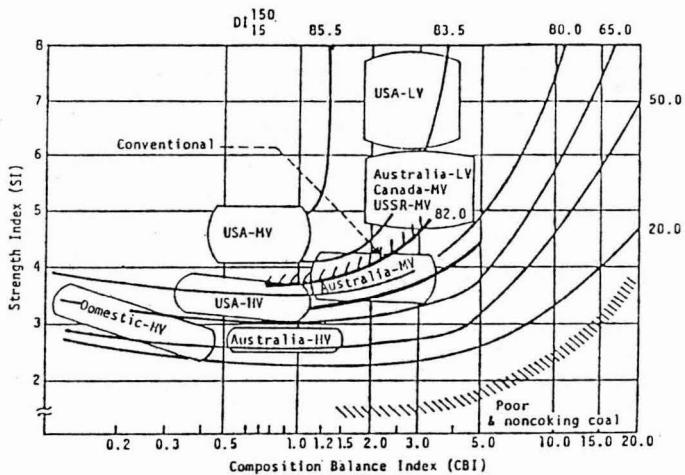


Fig.1 An example of classification of unblended coals by SI and CBI

| | | | | | | |
|----|-----|---|---|---|--|-----|
| MF | 3.5 | RLFH Low Rank High Fluidity Coal | RM ₂ FH Medium Rank No. 2 High Fluidity Coal | RM ₁ FH Medium Rank No. 1 High Fluidity Coal | RIFH High Rank High Fluidity Coal | |
| | 2.5 | RLFM Low Rank Medium Fluidity Coal | RM ₂ FM Medium Rank No. 2 Medium Fluidity Coal | RM ₁ FM Medium Rank No. 1 Medium Fluidity Coal | RIFM High Rank Medium Fluidity Coal | |
| | 0.5 | RLFL Low Rank Low Fluidity Coal | RMFL Medium Rank Low Fluidity Coal | | RIFL High Rank Low Fluidity Coal | |
| | | 0 | 0.7 | 1.1 | 1.5 | 1.9 |
| | | Ro | | | | |

Fig.2 Classification of coking coals by JAPAN IRON AND STEEL INSTITUTE

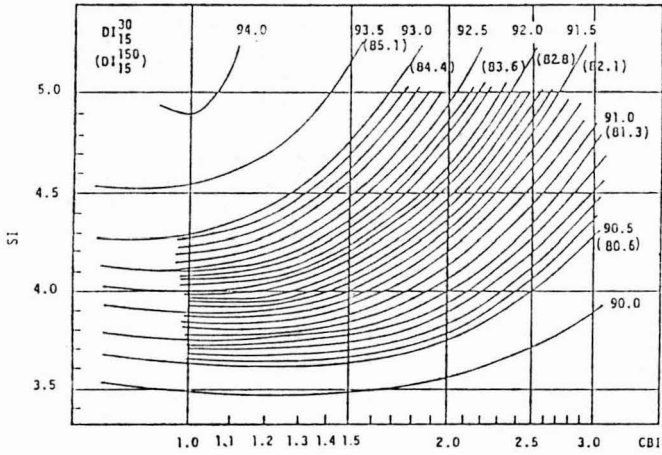


Fig.3 SI-CBI diagram for coke strength estimation

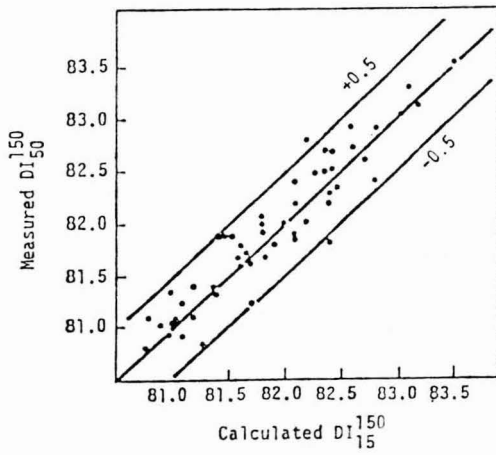


Fig.4 Relation between the calculated and measured coke strength

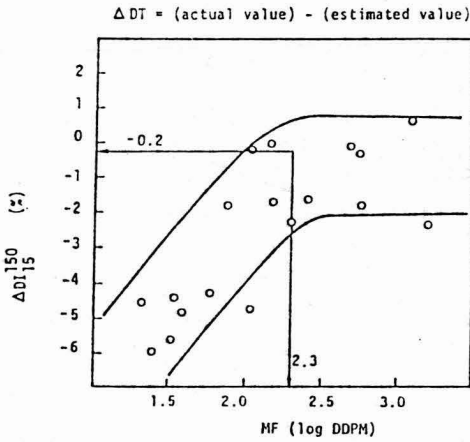


Fig.5 Deviation of estimated strength due to fluidity of blended coals

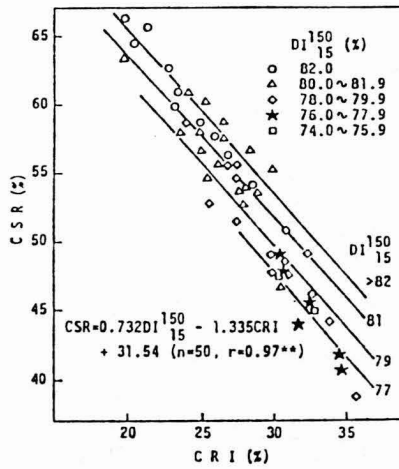


Fig.6 Relation among CSR, CRI and DI

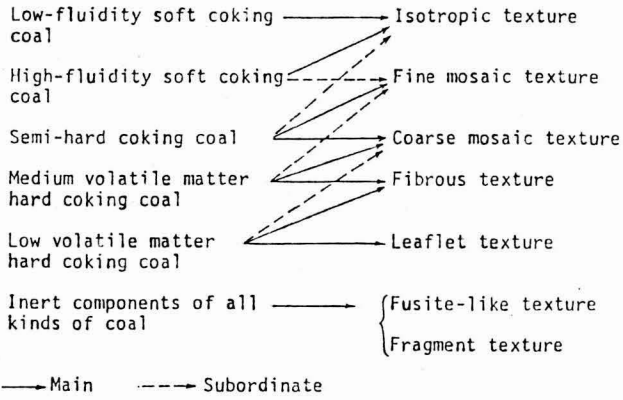


Fig.7 Correlation between optical anisotropic texture of coke and coking coals

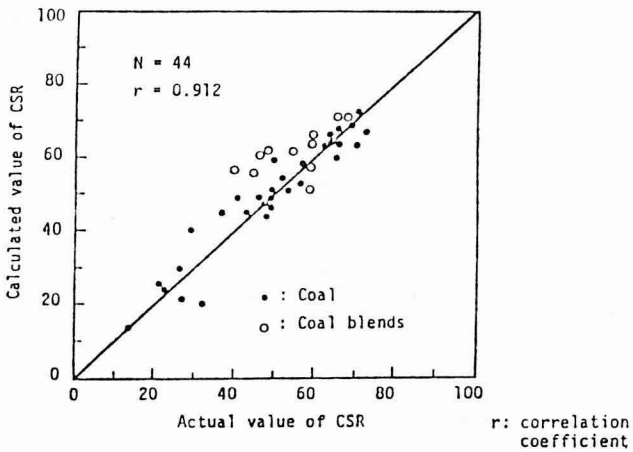


Fig.8 comparison of the calculated value with the actual of CSR

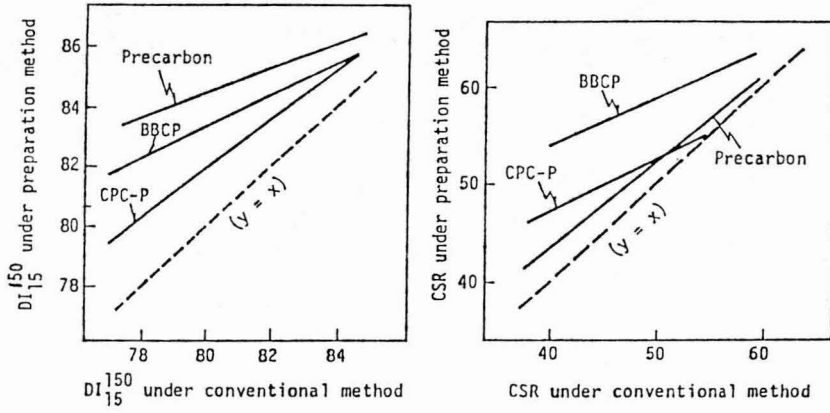


Fig.9 Effect of coal charge preparation on coke quality

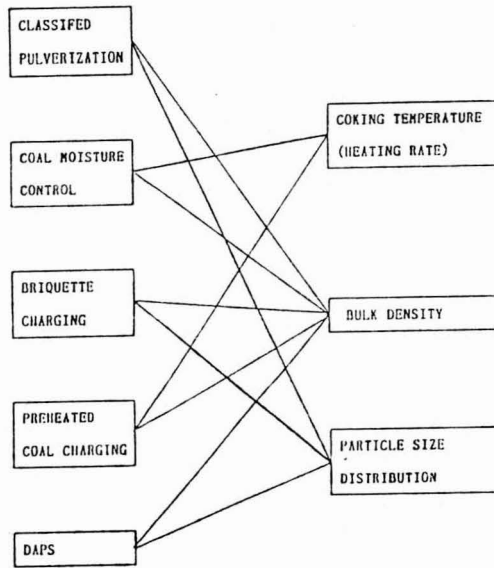


Fig.10 Changes in coking conditions by coal preparation

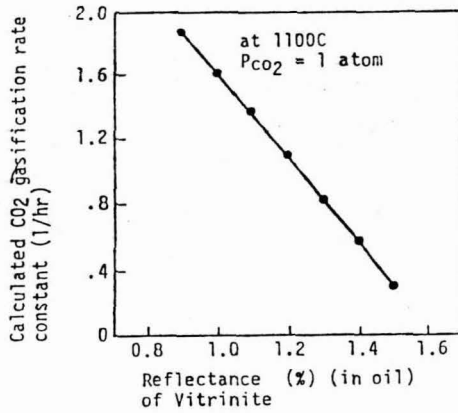


Fig.11 CO₂ gasification rate of coke from only inert maceral obtained from coals with different vitrinite reflectance by the specific-gravity method

| Country | Ro (Reflectance) | | MF (Fluidity) | | TI (Inert) | |
|-----------|------------------|-------------|---------------|-------------|------------|-----------|
| USA | 00 | < 0.5 | 0 | < 0.5 | 1 | < 20 |
| Australia | 06 | 0.5 ≦ < 0.7 | 1 | 0.5 ≦ < 1.5 | 2 | 20 ≦ < 40 |
| Canada | 08 | 0.7 ≦ < 0.9 | 2 | 1.5 ≦ < 2.5 | 3 | 40 ≦ |
| China | 10 | 0.9 ≦ < 1.1 | 3 | 2.6 ≦ < 3.5 | | |
| USSR | 12 | 1.1 ≦ < 1.3 | 1 | 3.5 ≦ < 4.5 | | |
| Japan | 14 | 1.3 ≦ < 1.5 | 5 | 4.5 ≦ | | |
| etc. | 16 | 1.5 ≦ < 1.7 | | | | |
| | 19 | 1.7 ≦ < 1.9 | | | | |
| | 99 | 1.9 ≦ | | | | |

Table 1 Coking coal classification codes