Coal Blending Theory—Retrospect and Prospect*

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Synopsis

This paper summarizes a series of experimental studies conducted by the author et al., on coal blending theory which is a basic condition for the production of coke. A brief history is given of the condition of coking coal supply and past studies undertaken in Japan ranging from the establishment of basic concepts of coal blending in the period immediately after World War II to recent trends in the search for blending standards aiming at the improvement of hot properties of coke. The essential point in coal blending is to obtain uniform, strong-textured coke as a composite material by an optimum combination of various grades of coal having different heating properties, i.e., thermal transformation temperatures. With the above-mentioned in mind, the paper describes the classification of single coal on the basis of the blending theory, the estimation of coke strength, and the theory for size control of coal charge. Finally, the relation among coal blending, coke texture, reactivity with CO₂, and strength after the reaction with CO₂ is described, indicating the importance of future efforts for the improvement of hot properties of coke by the addition of caking additive.

I. Introduction

Japan depends heavily on imports for its iron ore and coal requirements. Accordingly, it is an important task for coke experts to use imported coals most effectively in the production of metallurgical coke. Figure 1 shows the transition of coking coal consumption in postwar Japan. As seen from this figure, Japan imports coals with different properties from various countries in the world. Therefore, the study of coal blending has always been of importance in coke research.

For the future production of coke, development of techniques as described below is strongly desired to meet the technological and economic requirements for coke as a major energy source for pig iron production. Namely, efforts should be directed toward the development of techniques to meet the diversification of coking coal resources, techniques for the utilization of low-grade coal, techniques for energy saving, and techniques to satisfy stringent quality requirements from blast furnace operators.

It should be noted that in the development of such techniques, the relationships of factors relating to coke production may differ, though slightly, from those encountered in the past. Summarizing the factors relating to coke production into three groups: coal blending (B), pretreatment (P) and carbonization (C), the coke quality can be expressed as follows:

\[ \text{Coke quality} = f(B, P, C) \]

In the above relationship, \( B \) may be called the internal factor and \( P \) and \( C \) external factors, when viewed from the coke side.

In the days of rapid economic growth, the emphasis of study was placed on the internal factor, i.e., coal blending, because of narrower freedom in external factors (\( P \) and \( C \)), and top priority being given to the acquisition of the required quantity of coke. In the future, however, the ratio of contribution of external factors to coke quality will be increased with changes in the conditions of pretreatment and carbonization (e.g., operation at low productivity, and adoption of the coking process for blending the briquette and preheating process) or with the development of new production processes, such as formed coke process. On the other hand, non- or slightly caking coal, caking additives, etc., with new properties have found gradual application in coke production. When deciding coal blending, therefore, the combined effects of these factors must be taken into consideration. For this reason, the role to be played by the coal blending theory has become increasingly important. For the preparation of various plans in connection with the development of coking coal resources, purchase and allocation of coal, coke production, construction and operation of blast furnaces, etc., the estimation of coke quality on the basis of coal blending plans is required. In this respect, the importance of coal blending theory cannot be emphasized too much.

Against the background and needs described above, Process Technology R & D Laboratories, Nippon...
Steel Corp., have been conducting research on new production processes, such as briquette blend coking, formed coke, and binder addition, as well as on coal blending for the improvement of hot properties of coke on the basis of the results of many years of research undertaken by the Technical Research Laboratories of the former Yawata Iron and Steel Company in connection with coal blending. This paper summarizes the results of a series of these studies in a systematic manner, reviewing them from the standpoint of "study and development of coal blending theory".

II. Basic Concepts of Coal Blending

I. Coke Formation Process

For the production of lump coke for blast furnaces, it is necessary to soften and to melt a certain rank of coal, called coking coal, in the heating process. Before the explanation of coal blending, therefore, the process of forming coke from coking coal will be briefly described.

When heated, coking coal softens and melts at temperatures between 300°C and 500°C and solidifies at higher temperatures, thus forming the coke texture (optical anisotropic texture and pore structure). In this case, however, the forming condition or the coke texture to be formed varies with the rank or petrographic components of coal. Generally, a coke texture is formed through the following processes:

1) Generation of bubbles in the particles (vitrinite)
2) Growth of bubbles, and coalescence of bubbles
3) Swelling of particles
4) Bonding of particles with each other
5) Resolidification and formation of semi-coke

The texture of coke obtained as a result of the above-mentioned processes is roughly divided into two types; the flow bond type in which coal particles sufficiently melt and combine with each other as in the case of hard coking coal which exhibits high fluidity during softening and melting, and the contact bond type which occurs in the case of soft coking coal with low fluidity.

Figure 2 shows the relation between coal rank (C%, daf) and transformation temperatures, i.e., the temperature at which bubbles are generated in vitrinite particles, the temperature at which particles come into contact with each other and melt together, and the temperature at which the anisotropic structure is developed in vitrinite particles. As is evident from this figure, the transformation temperatures vary with coal rank.

Described above are the transformation temperatures in the coal heating process which were examined on a microscopic scale. Figure 3 shows the transformation temperatures in a macroscopic behavior which are quoted from the figure drawn by Krevelen. Namely, Fig. 3 shows the relation between coal rank and various characteristic temperatures in connection with fluidity (Gieseler's plastometer), dilatation (Audibert–Arnu's dilatometer) and degasification (thermal balance). It will be seen that the transformation (characteristic) temperatures vary considerably with coal rank in a manner similar to those shown in Fig. 2.

Summarizing these microscopic and macroscopic phenomena in which various transformation temperatures in the heating process vary considerably with coal rank, it is evident that coal blending is a basic prerequisite for obtaining a uniform coke texture as a composite material through an optimum
combination of these characteristics. The texture, structure and quality of coke are affected by external factors for coking, such as crushed size, size distribution, bulk density, heating rate, etc. Such effects will be described in the succeeding paragraphs.

2. Establishment of Basic Concepts of Coal Blending

1. Compatibility in Coal Blending

As the heating characteristics vary from coal to coal as described above, the optimum combination of coals is the essential point in coal blending. It is empirically known that coke of excellent quality can be obtained depending on combinations of coals. In the period from 1907 to 1909 in which modern coke ovens were constructed at Yawata Works, coke was produced by blending 20 to 30% Miike coal with Futase coal. It is said that expensive Taka-shima-coal coke produced in beehive ovens was added in a small quantity like a medicine when the blast furnace condition was poor. In 1910, Kaihei (Kailan) coal was imported from China for the first time. The coke strength was remarkably improved by blending Kaihei coal in an amount of 30%, and consequently BF condition was stabilized and the amounts of hot pig were increased. From then up to the start of World War II, blending of 70% Futase coal and 30% Kaihei coal, called "Gen-kai 73", was the standard practice.

It is said that Hashimoto was the first to suggest the compatibility problem in a definite manner in his report. His suggestion was based on the result of experiment that the strength of blast furnace coke produced by blending Japanese coals only varied with the kinds of coals blended. An example of his suggestion is shown in Fig. 4.

![Fig. 4. Compatibility in case when Ohyubari coal was blended with other grades of coal.](image)

2. Modeling of Concept of Compatibility

In the days before and after World War II (1943-1949) when difficulty was encountered in purchasing coking coal, Joh studied the reason why hard lump coke could not be produced from Japanese coals, based on the experience as described above. As a result, he modeled the concept of compatibility by introducing a new parameter, i.e., strength of fibrous component, in addition to caking property, and derived a basic concept of coal blending.

Dividing coal components into fibrous and caking components, Joh made clear that the strength of coke produced from Japanese coals was greatly affected by the properties of fibrous component which is the main component of coal. Based on this finding, he established the basic condition that the strength of fibrous component should be improved and the caking component should be well balanced with the fibrous component in order to obtain high-quality lump coke. He proposed a conceptual diagram as shown in Fig. 5.

In this figure, the black portions indicate the caking component, while the reticulated portions indicate the fibrous component. The larger the black portion, the larger the quantity of caking component, and the smaller the meshes, the higher the strength of fibrous component. The reason why high-quality coke can be obtained from hard coking coal may be that the quantity of caking component is appropriate and the strength of fibrous component is high. In other coals, such as anthracite, the strength of fibrous component is high but the quantity of caking component is not sufficient. In non-coking coals, the strength of fibrous component is not sufficiently high and the quantity of caking component is not appropriate. With soft coking coal, the strength of fibrous component is generally low. However, Fig. 5 shows that there are two types of soft coking coal; one that lacks caking component and one that contains an excessive amount of caking component. Since the properties of coals other than hard coking coal can be improved to nearly the same level as those of hard coking coal by blending coke breeze or pitch or by employing pressure forming as shown by the arrow marks in Fig. 5, these coals are usable for the production of high-quality coke.

Joh's theory is as described above. Since then, however, Japan has had to import various kinds of coal because of changes in the supplying situation of coking coal. To meet such situation, Miyazu et al., introduced the concept called fluidity domination or rank domination into the properties of coking coal as described in more detail later. Such concepts can also be derived from the above-mentioned Joh's theory. Namely, the strength of coke can be schematically defined as shown in Fig. 6 using the following two parameters:

- The strength of fibrous component should be high.
- Rank parameter*
The quantity of caking component should be appropriate for the caking property parameter. Based on this figure, the caking property dominated regions (I) and (II) and the rank-dominated region can be set for the strength of coke to be produced from blended coals. The basic relation as shown in Fig. 6 was reported not only by Miyazu et al., but also by Ida et al., Kojima and Schapiro and Gray. It is considered that this relation is highly acceptable.

3. Blending Parameter

When the basic concept of blending as shown in Fig. 5 is used for establishing the blending standard of coals two parameters, i.e., the strength of fibrous component and the quantity of caking component, are used. These are the parameters expressing the rank and caking property as described previously.

The strength of fibrous component is a new parameter introduced by Joh. This strength is expressed by the maximum compression strength of the coke to be obtained when the mixture of pyridine insoluble residue (α-fraction) of coal and an optimum amount of pitch is carbonized at 950°C for 15 min. This value shows a good correlation with the volatile matter of coking coal. In practice, therefore, the amount of volatile matter is used.

For the quantity of caking component, the amount of gas accompanied with the endothermic reaction caused at 400° to 500°C during the coal test employing a thermal analysis equipment was previously used. Since then, the rapid measuring method has been developed and undergone various improvements. At present, the method as described below is employed. Namely, a mixture of 1 g of sample (−210 μm) and 9 g of coke breeze (210 to 297 μm) is carbonized at 950±20°C for 7 min, and the yield of carbonization product larger than 297 μm is used as an index of the quantity of caking component. In about 1962, the name of this index was changed to "caking index (CI)" based on the results of subsequent study.

3. Development of Blending Parameters with Changes in Coking Coal Situation

For the rank and caking property to be used for the determination of coal blending, various parameters have been used because of differences in detecting power of respective parameters depending on the kinds of coal and of users' preference. These
parameters are reviewed and summarized below.

1. Period in Which Domestic Coal Was Used as a Main Material

This is the period before and after the war during which U.S. coal was not imported. As Japanese coal was generally low in rank, it may be considered that the coking coal was in the rank-dominated region. In this period, systematic studies of blending parameters were not conducted. Study employing the caking index and volatile matter was started with Joh’s theory.15,16

2. Period in Which U.S. Coal Was Used as a Main Material

With the start of import of U.S. coal, the method employing a Gieseler’s plastometer for determination of the parameter associated with caking property found wide application in Japan as the ASTM standard had adopted this method some time before.19

With the introduction of technical information from Europe and America, the method employing a European type Audibert–Arnu’s dilatometer found gradual application.20 In these methods, the volatile matter is used as a rank parameter.

3. Period in Which Many Brands of Coal Were Used

In this period, particularly after 1965, when the Japanese steel industry made rapid progress, a variety of coal, such as Australian, Soviet and Canadian coals, were imported to meet a sharp increase in coking coal consumption. Accordingly, requirements for the introduction of a scientific method for examination of these coals became stronger. On the other hand, a petrographic method for the microscopic examination of coal as an organic mineral was already in use. However, Ammosov et al.,21 and Schapiro et al,14,22 developed practical methods (in which the strength index (SI) and composition balance index (CBI) are used) from the coke producers’ standpoint. To meet the above-mentioned requirements, supplementary tests and improvements of these methods were attempted in Japan.13,23-25

These methods are excellent for the determination of properties of various brands of coal. When used in combination with various parameters, they will play an important role in the evaluation of coking coals from a variety of sources. They will undergo further improvements and developments so that more accurate parameters can be obtained for determination of coal blending. With regard to the simplification and speed of measurement which have been a bottleneck in practical application of these methods, an automatic measuring system26-28 developed by Nippon Steel Corp’s Fundamental Research Laboratories is already in practical use. In recent years, similar efforts are being made in many foreign countries. These efforts will make a great contribution to the development of parameter measurement.

II. Coal Blending and Coke Quality

1. Classification of Single Coal

As described previously, the establishment of blending standard is based on the assumption that coke strength (tumbler index) can be expressed by two parameters: caking property and rank of coal. Accordingly, the single coal to be blended must be classified by determining its properties in terms of these two parameters. As described in the preceding paragraph, there are a variety of parameters to be used for such classification. However, they may be summarized into five combinations as shown in Table 1.10 Single coal is classified according to these five combinations of parameters. Figures 7 and 8 show comparisons of the relative positions of various kinds of coal which were determined by overlapping the classification diagram of each kind of coal.

In the classification according to SI-CBI, the parameters differ in level. Accordingly, direct comparison was not made but the relative positions of coal groups were compared, the results of which are shown in Fig. 8.

Table 1. Combinations of parameters for classification.10

<table>
<thead>
<tr>
<th>No.</th>
<th>Rank parameter</th>
<th>Caking property parameter</th>
<th>Major Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Volatile matter (VM)</td>
<td>Caking index (CI)</td>
<td>(6), (7), (16), (29)</td>
</tr>
<tr>
<td>2</td>
<td>Volatile matter (VM)</td>
<td>Max. fluidity (MF)</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Volatile matter (VM)</td>
<td>Total dilatation (TD)</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>Average reflectance of vitrinite (Rv)</td>
<td>Max. fluidity (MF)</td>
<td>(9), (11), (23)</td>
</tr>
<tr>
<td>5</td>
<td>Strength index (SI)</td>
<td>Composition balance index (CBI)</td>
<td>13</td>
</tr>
</tbody>
</table>

Fig. 7. Comparison of classification diagrams of single coal.20
As is apparent from these figures, the relative position of single coal according to the first to fourth combinations of parameters is nearly the same. The only difference is the shift of position due to the difference in detecting power of each parameter (particularly the caking property parameter taken on the axis of ordinate). The relative position of single coal according to the fifth combination (SI-CBI) is nearly equal to those according to the other four combinations in spite of the difference in level of each parameter. The position of blending coal for coal charge is also shown in Figs. 7 and 8. The position of such coal determined by each combination of parameters was nearly the same.

As is apparent from the above description, differences in the classification of single coal by different combinations of parameters are attributed to the selection of measuring method of each parameter. The measuring method should be selected with the following two points taken into consideration.

1) Detecting power of each parameter for coal to be blended
2) Practical simplicity and accuracy of method

From the standpoint of detecting power, the caking property parameter is a major problem. The caking index is excellent for coal of inferior quality, but the maximum fluidity (MF) and total dilatation (TD) are excellent for coking coal. The strength index (SI) and composition balance index (CBI) are applicable to almost all kinds of coal. As shown in Fig. 8, however, these parameters are particularly applicable to coking coal. Concerning the simplicity and accuracy of measuring methods, each measuring method has merits and demerits, therefore, no method is definitely superior among them.

2. Estimation of Coke Strength

To estimate the coke strength from blended coal, the correlation between the rank and caking property parameters of coal and the experimentally determined coke strength index is utilized. In this case, the following factors must be taken into consideration.

1) Types of rank and caking property parameters to be used
2) Additivity between property indices of blended coal and single coal (rank and caking property)
3) Effect of coking conditions (pretreatment and carbonization)

At present, a perfect estimation method in which all of these factors are taken into consideration has not been developed yet.

With regard to the parameters to be used, it is considered that the SI-CBI method employing coal petrographic analysis or the VM-CI method with high detecting power for coal of inferior quality will become increasingly important in view of the potential diversification of coking coal sources or the necessity of using non- or slightly caking coal as described in the preceding paragraph. However, these parameters have a common problem as described below. Although the parameter employing the coal petrographic analysis (genetic property of coal) is scientific, parameters of practical use have not been developed yet. On the other hand, the parameters employing the so-called processing parameters, such as caking index, fluidity and dilatation, have been used for a long time and are based on the principle of coking, although they lack accuracy and detecting power. Accordingly, future efforts should be directed toward the use of processing property as a main parameter with genetic property as a supplementary parameter in consideration of the improvement of accuracy of strength estimation in the future.

Examples of diagram for coke strength estimation are shown in Figs. 9 and 10.

The additivity of caking property in blending coal has been established only analogously. In foreign countries, however, the quantitative estimation of additivity has been attempted. This should be studied in the future to meet the requirements for more accurate strength estimation.

With regard to the effect of coking condition, coke quality is greatly affected by this condition. Each condition has been individually studied, particularly when a new technique or process was developed. In the future, however, the above-mentioned three conditions should be studied in a comprehensive manner. For the purpose of the present discussion, size control which is one of the basic conditions of pretreatment will be described below.

3. Coal Blending and Size Control of Coal Charge

The purpose of size control is to optimize crushed coal size and size distribution. The grindability of coal varies considerably with rank and petrographic component. On the other hand, the caking prop-
property of coal varies not only with rank and petrographic component but also with coal particle size. For size control of blended coal, therefore, it is necessary to optimize these conditions.

1. Grindability

Figure 11 shows the relation between grindability (Hardgrove index, HGI\textsuperscript{27}) and rank. As is apparent from this figure, the HGI of hard coking coal, soft coking coal and non-coking coal decreases in the order mentioned. According to the results of study on HGI of petrographic components,\textsuperscript{28} vitrinite-rich particles are easy to grind but durite-rich particles are hard to grind.

2. Kinds of Coal Particles as Viewed from Heating Properties

Coke formation begins with bonding of coal particles upon heating. Coal particles contain a variety of petrographic components and the behavior of each type of petrographic component differs considerably. When studying the caking property of petrographic components, therefore, the components are generally defined as follows:

Reactive components: Components which soften and melt upon heating (vitrinite, exinite, etc.)

Inert components: Components which do not soften and melt upon heating (interrinite, mineral matter, etc.)

Accordingly, components that pyrolyze or polymerize chemically but do not soften and melt are not included in reactive components. In other words, components with thermoplastic property are called reactive components. Thus, study of crushed coal particles will be made, dividing them into reactive particles, consisting mainly of reactive components, and inert particles, consisting mainly of inert components. It is clear that the contents of these particles vary with the kind of blended coal.

3. Behavior of Reactive Particles on Heating\textsuperscript{29}

In the effect of coal size during the heating of coal, reactive particles play the most important role. Generally, coarse particles give favorable effect on particle bonding, though the degree of this effect varies with the brand and rank of coal.

Samples having different particle size were prepared for four kinds of coal which were Itmann, Ohnoura, Standard Douglas and Coal Cliff. Carbonizing these samples at temperatures up to about 600°C, the transformation temperatures of coal particles (reactive particles) during heating were examined by using a microscope. The results are shown in Fig. 12. For comparison of swelling property, the dilatation was examined with a dilatometer. The results are shown in Fig. 13. In this test, as the particle sizes of samples were not controlled, the bulk density of all samples was adjusted to 0.70 g/cm\textsuperscript{3} when they were charged into the dilatometer tube.

As is apparent from these results, the transformation temperatures of particles of all kinds of coal shift toward the high temperature side as their sizes become smaller, resulting in a decrease in dilatation. In other words, it may be considered that the reactivity of particles decreases as their size decreases.

4. Behavior of Inert Particles on Heating

In the coking process, lump coke is formed when the particles are bonded with each other as inert components are wrapped in the reactive components that have softened. In this case, the inert components act to impart strength to lump coke.
If the caking property of coal is considered synonymous for the macroscopic strength of the product coke, the intrinsic strength of coke resulting from the bonding of coal particles and the fissure (internal stress) in coke lumps must be considered. Studying the role of inert components (particles) from this standpoint, it will be seen that the improvement of wettability and solubility with reactive components (intrinsic strength) and the improvement of uniformity of texture of coke lump produced (prevention of fissure and internal stress) are important. For this reason, the inert components should be as small in size as possible. On the other hand, the reactive components should be desirably coarse as described previously. To obtain the optimum size of coal particle, therefore, it is necessary to decrease the variations in size of inert components and to minimize their surface area so as to ensure a balance with reactive components as pointed out by E. Burstlein (SOVACO process).

In practice, this optimum particles size varies with the rank, caking property, petrographic components, etc., of coal. This relation becomes more complex in the case of blended coal. An example of this relation is described below with reference to Coal Cliff coal.

Coal Cliff coal was screened by sizes and the coal in each size range was subjected to petrographic analysis and coking test in box to examine coke strength, the results of which are shown in Table 2. Coking test was conducted using three sizes, namely uncrushed size, normally crushed size (-6 mm) and finely crushed size (-0.3 mm). The following will be seen from Table 2.

1. Coarse particles contain a smaller quantity of reactive components (vitrite) but larger quantities of inert components (durite and fusite).
2. The strength of coke made from coarse particles containing larger quantities of inert components shows a high value when it is crushed to sizes below -6 mm, but decreases when it is crushed to -0.3 mm, evidencing overcrushing.
3. The coke made from fine particles containing larger quantities of reactive components shows a sufficiently high strength, regardless of whether it is crushed to -6 or -0.3 mm. It may be said that inert and reactive components are well balanced in size ratio.

5. Coal Blending and Size Control

For size control, many tests and studies have been conducted in the world, but a systematic theory has not been established yet, because coal is a very complex organic mineral and the coking mechanism has not been fully elucidated.

Since control has two purposes as described below.

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*Fig. 12. Relation between coal particle size and transformation temperatures.*

*Fig. 13. Relation between coal particle size and swelling property.*
(1) Ensuring the Macroscopic Uniformity

Macroscopic uniformity depends on how the crushing and blending methods are selected to obtain the optimum size distribution of coal charge. For this problem, many studies have been undertaken to date as represented by the SOVACO process (Longwy-Burtsleln process). In Japan, this problem is particularly important as many brands are being blended. As this is an important pretreatment process of coal charge in the production of coke, many improvements are being attempted. The size distribution of coking coal is also receiving much attention in an effort to improve the bulk density which is another important factor.

Figure 14 shows typical examples of the relation among size distribution, bulk density and the strength of coke produced. The classifying point on the axis of abscissa indicates the mesh size in the case that the coal charge was prepared by crushing oversizes only. It is clear that the size distribution varies with the classifying point. As is apparent from Fig. 14, the coke strength increases with increasing bulk density. However, the coke strength varies considerably with size distribution even if the bulk density is the same. When a bulk density corresponding to that used in conventional slot type ovens is used, the coke strength becomes highest at a classifying point of 5 mm, an increase of 2.5 as compared with that in the case of normal crushing. In the case of normal crushing of coal charge, the classifying point is not provided (a screen is not used) and particles of $-3 \text{ mm}$ account for 80 to 90%. In this case, a considerably large quantity of coarse particles (inert hard particles) are present as the upper limit is not set for the particle size. Accordingly, the coke texture is non uniform and cracks are likely to generate from coarse particles, resulting in a decrease in strength. If the coal is screened to 3 to 5 mm, however, coarser particles can be eliminated and the coke texture becomes uniform, leading to improved strength.

(2) Optimization of Particle Bonding Condition

From the microscopic standpoint, the swelling property of particles decreases as described in the preceding paragraph if particles are too small in size. As a result, the caking action between particles is obstructed. As the degree of such obstruction varies with the brand and petrographic components of coal, the optimum particle size of blended coal varies with the brand of coal. Recent trend is toward crushing each brand or brand group of coal separately before blending.

<table>
<thead>
<tr>
<th>Particle size (mm)</th>
<th>Volatile matter (% d)</th>
<th>Petrographic analysis</th>
<th>Coke strength (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Not crushed</td>
<td>Crushed to $-6 \text{ mm}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_{0.1}$</td>
<td>$T_{1}^{400}$</td>
</tr>
<tr>
<td>$+20$</td>
<td>19.8</td>
<td>9.5</td>
<td>46.9</td>
</tr>
<tr>
<td>$20\sim10$</td>
<td>20.0</td>
<td>9.1</td>
<td>55.6</td>
</tr>
<tr>
<td>$10\sim6$</td>
<td>20.8</td>
<td>13.8</td>
<td>55.8</td>
</tr>
<tr>
<td>$6\sim3$</td>
<td>20.5</td>
<td>17.4</td>
<td>55.1</td>
</tr>
<tr>
<td>$3\sim1.5$</td>
<td>20.8</td>
<td>20.5</td>
<td>51.2</td>
</tr>
<tr>
<td>$1.5\sim0.6$</td>
<td>21.9</td>
<td>38.1</td>
<td>23.5</td>
</tr>
<tr>
<td>$0.6\sim0.3$</td>
<td>22.6</td>
<td>50.9</td>
<td>32.5</td>
</tr>
<tr>
<td>$-0.3$</td>
<td>22.9</td>
<td>51.6</td>
<td>35.6</td>
</tr>
<tr>
<td>Original coal</td>
<td>21.9</td>
<td>26.8</td>
<td>44.4</td>
</tr>
</tbody>
</table>

Table 2. Properties of Coal Cliff by particle sizes and coke strength.*

* Box test at 1200°C for 16 h.

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Report
4. Coal Blending and Hot Properties of Coke

1. Properties of Coke at the High-temperature Zone of Blast Furnace

Concerning the deterioration of coke at the high-temperature zone of blast furnace (hearth and combustion zone in particular), the following findings were obtained as a result of the dissection of Higashida No. 5, Kukioka No. 4 and Hirohata No. 1 blast furnaces. The structure of coke becomes porous and weak in the blast furnace because of the solution loss by the selective gasification of coke texture with CO₂. It is, therefore, considered that coke is disintegrated due to the abrasion caused during its descent in the furnace or collision with the raceway.

As coke is exposed to considerably severe external conditions at the high-temperature zone of blast furnace as described above, coke with excellent hot properties which does not deteriorate at the high-temperature zone is strongly required. For evaluation of coke quality, the testing method for the strength after the reaction with CO₂ was developed, and the existence of a significant correlation was reported between the blast furnace operating condition and the strength after the reaction with CO₂. From the standpoint of blast-furnace operation, size control at the high-temperature zone has come to attract wide attention.

2. Reactivity of Coke with CO₂ and Strength after the Reaction with CO₂

When coke is reacted with CO₂ in the blast furnace, it is partly gasified and the strength of the remaining part decreases, leading to the final disintegration to the fines. The relation among factors in this period can be arranged as shown below:

\[ V \propto \left(1 - f_2 \right) K_2 D_2 \]

where, \( V \): rate of coke fine evolution
\( f_2 \): marginal gasification ratio
\( K_2 \): reaction rate constant (volume base) of lump coke
\( D_2 \): effective gas diffusion coefficient in coke particles

\( f_2 \) and \( K_2 \) are the terms which are related to the property of coke matrix, i.e., optical anisotropic component. \( D_2 \) is considered to be the term relating to coke pores.

As the quantitative analysis of each factor, particularly the relation with the properties of single coal from the standpoint of coal blending, involves complicated conditions associated with the carbonization mechanism of blended coal as a parameter, future study is required. In recent years, several reports, though fragmentary, have been published on this problem. However, many of these reports deal with the relation with the properties of blended coal or coke to be produced from such coal, and only few reports discuss the relation with the properties of single coal.

The following relation has been found between the kind of coking coal and the microstructure of coke produced from such coal.

- Low-fluidity soft coking coal: Isotropic texture
- High-fluidity soft coking coal: Fine mosaic texture
- Semi-hard coking coal: Coarse mosaic texture
- Medium volatile matter hard coking coal: Fibrous texture
- Low volatile matter hard coking coal: Leaflet texture
- Inert components of all kinds of coal: Fusite-like texture

Namely, coke with well-developed anisotropic structure can be obtained from coal with high rank.

Figure 15 shows the results of the study on the reactivity of these coke textures with CO₂. As is seen from these results, the isotropic texture shows the highest reactivity, then come the fragment texture, fusite-like texture and fine mosaic texture. The coarse mosaic texture, fibrous texture and leaflet texture are the lowest in the reactivity.

The larger the quantity of inert components in coking coal, the higher the reactivity of the coke produced. When the rank is high, however, the reactivity decreases even if the quantity of inert com-
ponent is large. This relation is illustrated in Fig. 16.

3. Improvement of Hot Properties
In recent years, studies on the improvement of hot properties of coke in the blast furnace have been started, because more importance has been attached to these properties and gradual decrease in the quality of coking coal and increased use of non- and slightly caking coal are expected in the future. As these studies are still underway, a conclusion in concrete shape has not yet been drawn. It has been, however, made clear that the anisotropic texture of coke can be developed by the addition of caking additive, leading to the improvement of hot properties. Figure 17 shows that the strength of coke added with a caking additive after the reaction with CO₂ becomes higher even if the amount of coke reacted with CO₂ is the same.

IV. Conclusion
The reduction of coke cost is one of the most important keypoints for the energy-dependent-steel-industry to get over in this day of expensive energy. For coke oven operators in Japan which imports most of its coking coal, the effective utilization of various kinds of coal has been and will be a difficult task.

To this target, the first prerequisite is to establish the blending theory for various kinds of coal. Hitherto, coal blending has been determined, placing emphasis mainly on the strength of coke at ambient temperature. To meet the diversification of coking coal sources (including the use of non- and slightly caking coal, caking additive, etc.), however, the blending theory must be established, setting the goal for the improvement of hot properties of coke. The establishment of the foundation of such theory is now underway.

To survive the future keen competition for technological development, the steel industry must change its empiric oriented technology to theory-oriented technology. It is the coal blending theory that plays an important role in such changes of coke production technology.

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