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Investigation of Strength Difference between Dry Quenched and Wet Quenched Coke

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The body can be viewed from the next page.

Investigation of Strength Difference between Dry Quenched and Wet Quenched Coke*

Tsugio MIYAGAWA ** Shunji ITO **

This paper discusses strength difference between dry quenched (DQ) and wet quenched (WQ) coke in terms of breakage behavior by regarding coke as one of brittle materials. DQ and WQ coke, produced under the same conditions except for the quenching process, were used in the following experiments: ① the revolving drum test to measure strength difference between size groups, ② the static loading test with disc-shaped specimens to evaluate structural microdefects such as microfissures, and ③ the compressive fracture strength test on irregular-shaped lump coke to estimate macrofissures. Except for large open fissures not assessed in these experiments, there is practically no difference between the two types of coke in the quality and the distribution of relatively large Griffith-type cracks, which control the breakage of lump coke in the static loading test. Once the cokes are subjected to impact forces, however, a difference in strength occurs between them. This implies a propagation of macrocracks originated from microdefects by the impact; therefore, WQ coke having many structural microdefects seems to be considerably affected in its breakage strength. It is concluded that the strength improvement by coke dry quenching process is mainly attributable to the fact that the DQ coke has few structural microdefects in coke.

1 Introduction

In these years, the coke dry quenchers (CDQ) have been widely used, and at Chiba Works, Kawasaki Steel Corporation, about 95% of coke used for the blast furnace is treated by the CDQ. The main purpose of CDQ is not only to save energy consumption, but also to improve coke quality and the stable operation of the blast furnace.

While there is a report[1] on the effects of CDQ treatment on the coke quality, the factors affecting the mechanical strength of coke which is particularly important for the blast furnace operation have not yet been elucidated. It is expected that the dry slow-cooling causes less internal cracks and residual strain in coke lumps than in the wet quenching (rapid cooling with water). These factors for improving strength have some common elements with factors determining the coke strength in the coking process[2]. In order to utilize the CDQ as a means of saving the coal cost, it is necessary to clarify the effects of slow cooling in distinction from the improvement of strength due to frequent suffering from extraneous mechanical impacts, which is called "stabilizing effects".

In the present report, the properties of wet and dry quenched coke were examined from the standpoint of materials mechanics, regarding coke as porous fragile materials, for the purpose of directly grasping the causes for improving the strength.

2 Experiments

2.1 Specimens

From the No. 6 Coke Oven at Chiba Works, 350 kg samples of wet quenched (WQ) coke collected at the wharf and dry quenched (DQ) coke collected immediately after the treatment at No. 1 CDQ were each taken. Both coke types were manufactured under the identical conditions except for the quenching method. The properties of coal charge are shown in **Table 1.**

The sample coke was sieved to six grades of coke size: $>$ 75 mm, 75–50 mm, 50–40 mm, 40–30 mm, 30–20 mm and $<$ 20 mm. The large coke above 30 mm were mainly used as specimens for the strength test.

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** Research Laboratories

Table 1 Properties of coal charge

Blending ratio of coal charge(%)			Proximate analysis(%)			Gieseler fluidity DDPM	Degree of crushing (-3mm%)
Coking coal	Soft coking coal	Caking coal	Ash	Volatile matter	Total sulfur		
60.5	23.5	16.0	8.4	29.1	0.59	411	81.4

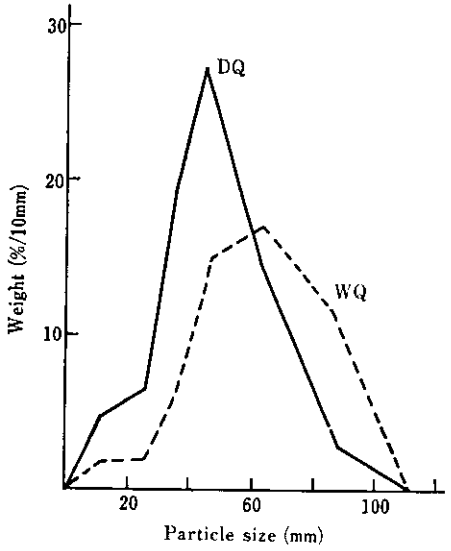


Fig. 1 Coke size distribution curve

Table 2 Analyses of sieved coke

Coke size(mm)	Proximate analysis		True density	JIS reactivity $\left(\frac{CO}{CO_2+CO}\%\right)$
	Volatile matter(%)	Ash(%)		
WQ coke 20~30	0.7	11.0	1.95	17.5
30~40	0.9	11.0	1.94	16.1
40~50	0.7	11.5	1.94	16.8
50~75	0.7	11.5	1.94	17.0
75~	0.8	12.2	1.94	22.0
DQ coke 20~30	0.8	11.6	1.95	14.2
30~40	0.6	11.8	1.94	13.5
40~50	0.6	11.4	1.95	14.0
50~75	0.5	11.0	1.95	16.5
75~	0.5	11.5	1.95	16.1

The particle size distributions in the both coke types are shown in **Fig. 1** in terms of a 10 mm particle size pitch. The proximate analysis, true density and JIS reactivity of each size cokes are given in **Table 2.** Each size cokes was divided into three groups and provided to the following three experiments, respectively.

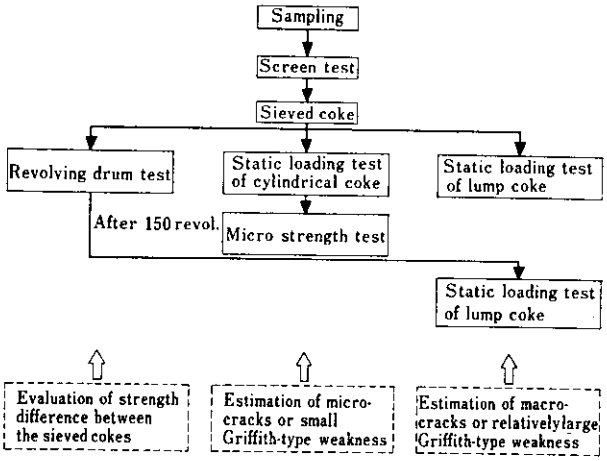


Fig. 2 Purpose and scheme of experiments

2.2 Experimental Method

The principal purpose of the present experiment is to grasp quantitatively the effect of reduction in the internal stress within coke matrix, as a result of slow cooling in the CDQ process. The purpose and scheme of the experiment are shown in **Fig. 2.**

2.2.1 Revolving drum test

In order to estimate the difference in revolving strength between coke groups of different particle sizes, the revolving drum test was carried out with specimens described in the preceding subsection. The drum testing machine agrees with the specification of JIS K–2151 except for its drum length of 500 mm. In a single test run, 3 kg specimen was used.

For the purpose of comparing strength between specimens of different initial particle sizes, the strength was evaluated in terms of average particle size change ratio, K, before and after the test, as given by the eq. (1)[3].

$$K = \frac{D_n}{D_0} \times 100 \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

D_0: Average particle size before testing
D_n: Average particle size after n revolutions

In calculation of the average particle size after the test, the values of particles smaller than 6 mm in diameter were eliminated.

2.2.2 Static loading test of cylindrical coke

In order to estimate the effect on minute structural defects within matrix such as microcracks, the indirect tensile strength test which consists of the static loading test and the calculation for conversion of the obtained data to tensile strength was carried out with cylindrical specimens cut out of coke lumps.

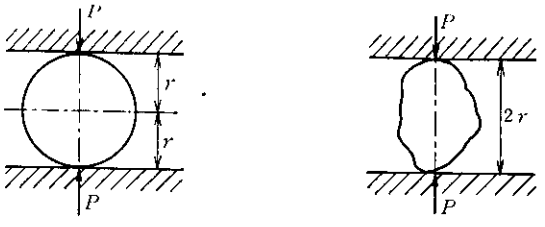


Fig. 3 Loading test of lump coke

50 or more cylindrical specimens were cut out from each size cokes. The preparation of specimens and the testing method were the same as reported elsewhere[4]. The thickness of a cylindrical specimen was changed from 5 mm in previous report to 10 mm, in consideration of the evaluation of internal cracks. At the same time, the micro-strength test was conducted with specimens which had been subjected to the strength test. The testing method was the same as the usual one in which the strength was defined as weight percentage of coke particles remained on +28 mesh and +65 mesh sieves.

2.2.3 Static loading test of lump coke

Irregular-shaped specimens of lump coke were subjected to the static loading test in order to estimate the effects on cracks in lump, mainly macroscopic structural defects. Hiramatsu et al.[5] proposed a method to determine the tensile strength quickly from the static loading strength of irregular-shaped rock specimens. Kanda et al.[6] confirmed that this method was effective on various kinds of fragile specimen. For details of this method, see the reference cited. The tensile strength S (kgf/cm^2) calculated from the fracture strength P (kgf) obtained with a spherical specimen shown in **Fig.** 3(a) by eq. **(2)** can be applied to the irregular specimen shown in **Fig.** 3(b). The particle size can be represented by distance $2r$ between loading points.

$$S = \frac{1.4P}{2\pi r^2} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

First, 20 specimens of different particle size were subjected to the preliminary static loading test. A simple compressive load testing machine of maximum load 10 t (manufactured by Yoshida Seisakusho, with load-displacement curve recorded on an X-Y recorder) was used with loading rate of 10 mm/min. The load was applied to a coke lump in the direction of furnace width. While some of porous specimens were crushed, most specimens were cleaved along a vertical plane

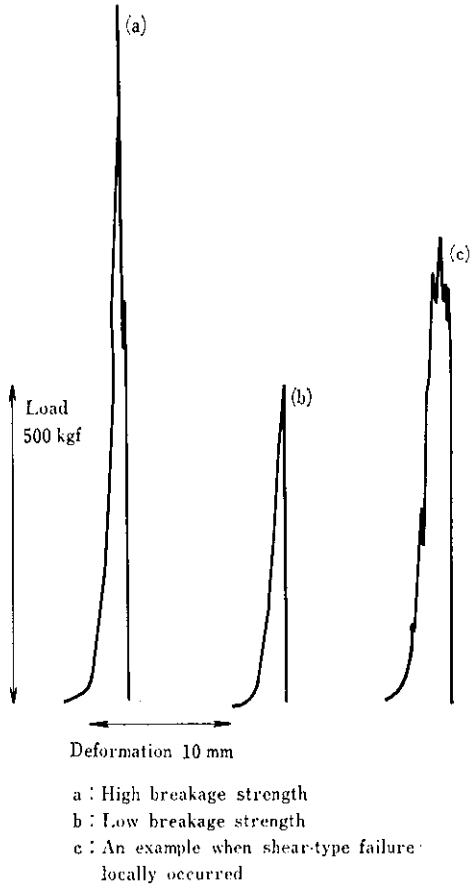


Fig. 4 Examples of load-deformation curves of lump coke

from the loading point, suggesting that the fracture was induced by the tensile stress vertical to the direction of compression. The fracture was similar to that of cylindrical specimen. An example of load-deformation curve recorded with the X-Y recorder is shown in **Fig. 4**.

Sieved cokes of a group described above and stabilized ones which had been subjected to the revolving drum test were used as specimens. As the fluctuation of strength values was expected, it was attempted to take as many measurements as possible. While irregular-shaped specimens were used as a rule, those which were so irregular as to be unsuitable for the strength test were cut and polished with emery paper to be nearly spherical without applying appreciable impact. The distance, $2r$, between loading points on the coke lump was exactly measured with calipers and the lump was weighed, before being put to the static loading test. The lump volume was calculated on the basis of mean apparent density obtained in 2.2.2 and the weight.

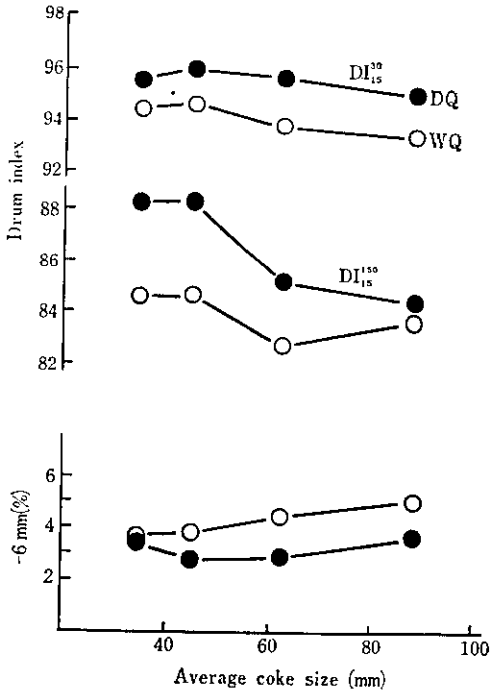
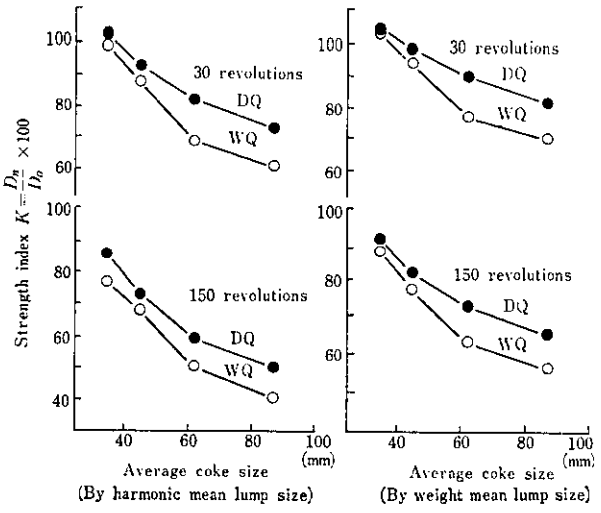


Fig. 5 Drum index of sieved coke



D_0 : Average mean size before revolu.
D_n : Average mean size after revolu.

Fig. 6 Evaluation of coke strength by *K*-value of sieved coke

3 Results and Discussion

3.1 Drum Strength of Sieved Coke

The strength of sieved coke is shown in **Fig. 5** in terms of the conventional strength index. In every particle size, the strength of DQ coke was higher than that of WQ one. In both coke species, the smaller the particle size, the higher the strength, and as the number of revolutions increased, the strength difference between two coke species tended to grow. Since it is questionable to compare the strength of specimens of different initial particle sizes simply in terms of yield on +15 mm sieve, it was attempted to evaluate the strength with the ratio (*K*-value) of average mean coke size before and after revolution test as defined by the eq. **(1)**, so as to make strength value compatible. Stepanov et al.[3] proposed that the change ratio of weighted mean lump size representing the volume change be regarded as a measure for crush resistance, and that the change ratio of harmonic mean lump size representing change in specific surface area be regarded as a measure for abrasion resistance. Since the mechanism of the coke breaking in the drum is not clarified at present, it can not be decided whether or not this strength estimation method is pertinent. However, it may be considered as a means for comparing the specimens of different initial lump sizes.

The *K*-values of sieved coke are plotted against the mean lump size in **Fig. 6**. For both DQ and WQ cokes, the smaller the lump size, the higher the *K*-value; and the greater the initial lump size, the greater the difference in *K*-value between two types of coke. While the strength evaluation of mean lump size in terms of weighted mean lump size gave nearly equal results as in the case of harmonic mean lump size, the difference of strength between two types of coke tended to increase in the latter method with increased number of revolution. The results may be summarized as below.

(1) In any of lump sizes, the strength of DQ coke was higher than that of WQ coke.
(2) For both types of coke, the smaller the lump size, the higher the strength.

3.2 Evaluation of Micro-cracks by Indirect Tensile Strength

In carrying out the static loading test with cylindrical specimens, those having defects which could be recognized visually as cracks were excluded so as to be compatible with the evaluation of micro-cracks. Such exclusion did not affect the extensive fluctuation in the tensile strength as in the case of results reported elsewhere[4]. As this tendency was common to all fragile specimens, the strength was evaluated in terms of fracture probability for the data analysis, as in the ceramic material test.

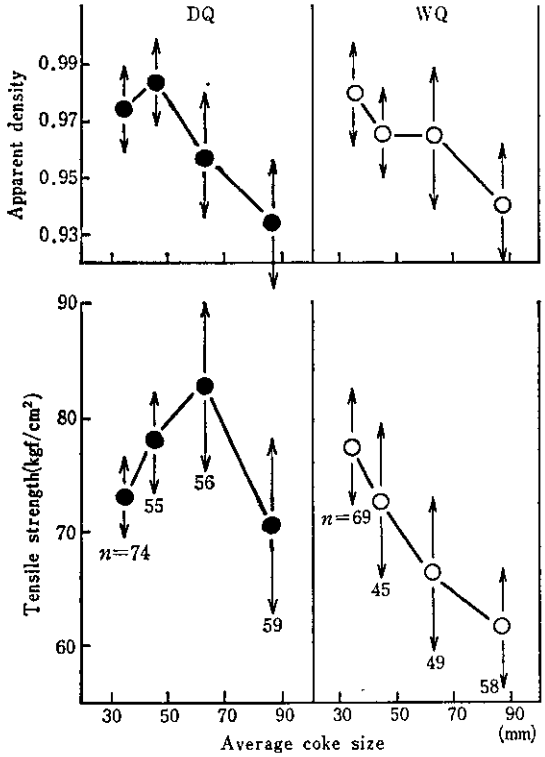


Fig. 7 Apparent density and tensile strength of cylindrical pieces of sieved coke

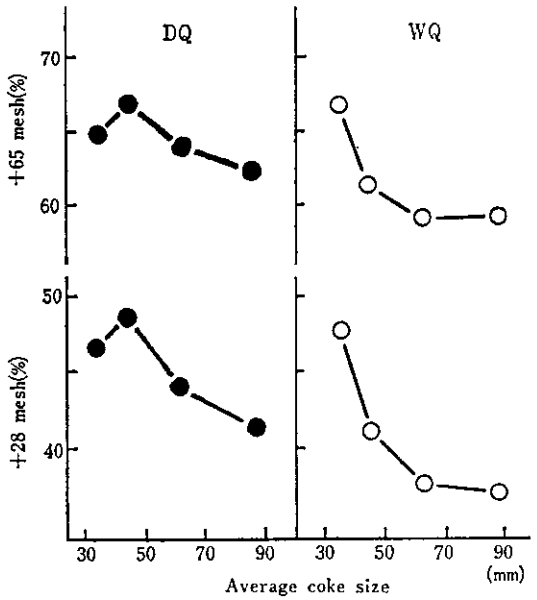


Fig. 8 Micro strength of sieved coke

3.2.1 Tensile strength of sieved coke

Figure 7 shows the apparent density and tensile strength values of cylindrical pieces of sieved coke against the average lump size. Arrows indicate the interval estimations at the confidence limit of 95% probability, with the number of specimens, n, written in the graph. In case of WQ coke, the greater the lump size, the lower the strength, in correspondence with the tendency of revolution strength described above. There was no definite trend in case of DQ coke, and the strength curve presented a maximum at a 50–75 mm lump size interval. This phenomenon is ascribed to the fragile parts of large-lumped DQ coke being shifted to smaller-lump group under the impact in the CDQ.

The micro-strength of specimens used for the tensile strength test is shown in **Fig. 8**. The strength changed in parallel with the trend of apparent density is shown in **Fig. 7**. Since WQ and DQ cokes have identical true density (see **Table 2**), the micro-strength representing the matrix strength depends upon the porosity. Based on the results in **Fig. 8**, the shift of fragility in DQ coke toward the smaller lump size side as described above may not always be attributed to the fragility of matrix.

The tensile strength of sieved WQ and DQ cokes was compared above. In order to grasp the overall effects of quenching method on strength, the discussion in the next subsection will be made with parameters pooled for various lump size groups.

3.2.2 Evaluation based on Weibull parameter

The mean apparent density and tensile strength (kgf/cm²), as calculated by pooling for various lump size groups, were 0.963 ± 0.009 and 75.6 ± 3.0 ($n = 244$) for DQ coke, and 0.963 ± 0.010 and 69.8 ± 3.0 ($n = 221$) for WQ coke, respectively. The statistical analysis revealed that there was no significant difference in apparent density, but there was a significant difference in tensile strength at the level 1%. As the true density was identical between two types of coke (see **Table 2**), the porosity was not significantly different. Moreover, since both the quality of charge and the carbonization conditions were identical with each other for both cokes, the difference in tensile strength may be attributed to the minute structural defects including micro-cracks within coke matrix.

Generally speaking, the fracture of fragile materials follows the Weibull distribution based on the weakest link theory, and the cumulative fracture probability F is given by eq. **(3)**[7].

$$F = 1 - \exp\left[-V\left(\frac{S - S_u}{S_0}\right)^m\right] \quad \cdots\cdots\cdots (3)$$

Where, S_u and S_0: Constants determined experimentally (S_u: Possible minimum strength, S_0: Scale parameter (normalization factor) specific to substance); m:

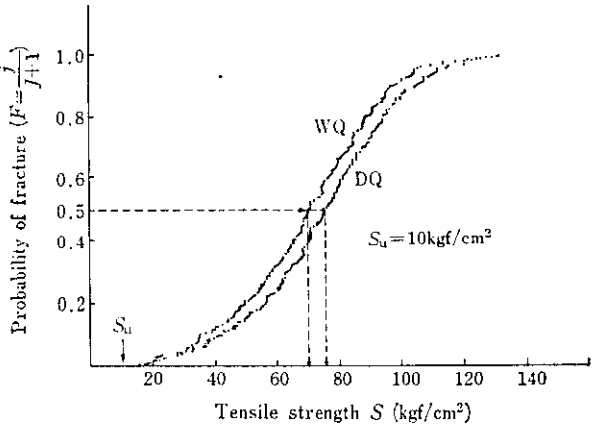


Fig. 9 Distribution curve of tensile strength of cylindrical coke

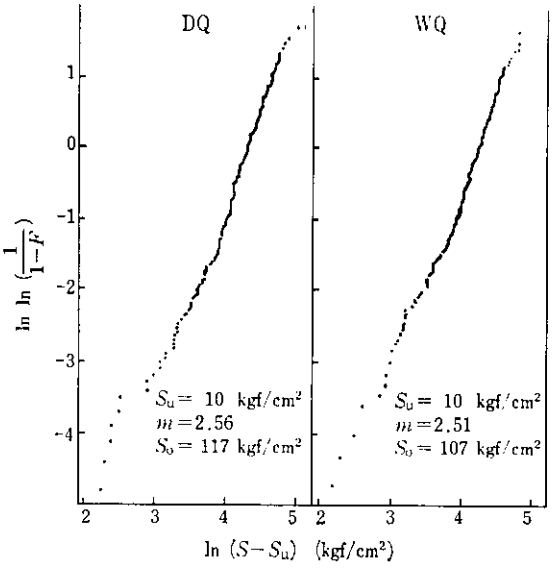


Fig. 10 Weibull plot of tensile strength of cylindrical coke

Parameter (Weibull parameter) related to the homogeneity of substance; the greater the m, the higher the homogeneity. In **Fig. 9**, the fracture probability $F = j/(J + 1)$, where J denotes the total number of measurements and j the j-th strength, is plotted against the tensile strength in an increasing order. The eq. **(3)** may be rewritten as **(4)**. $S_u = 10$ kgf/cm² is obtained from **Fig. 9**.

$$\ln \ln \frac{1}{1-F} = m \ln \frac{S - S_u}{S_0} + \ln V \quad \cdots\cdots (4)$$

In **Fig. 10**, $\ln \ln 1/(1 - F)$ is plotted against $\ln(S - S_u)$. Since the curve was nearly linear, with simple correlation coefficient $r = 0.985$ for DQ coke and $r = 0.993$ for WQ coke, Weibull parameter m and S_0 as calculated from eq. **(4)** are shown in the figure. The volume of cylindrical specimen was used as the value of V. The statistical analysis described here revealed a significant difference in strength represented by parameter S_0 between the two types of coke, as in the case of tensile strength described above. It is not clear whether the difference is due to a quantitative factor, namely, the number of minute structural defects, or due to a qualitative factor, namely, the structure of defects based on the weakest link theory. It is infered, however, that there is little difference in the fluctuation of fracture strength due to minute structural defects between two types of coke.

3.2.3 Attempts to quantitize minute structural defects

In the preceding subsection, the analysis through the Weibull statistics was attempted regarding coke as porous fragile materials. In case of similar analysis for ceramic fragile materials which may be regarded as randomly heterogenous materials with irregular internal structure, the value of Weibull parameter is normally $m > 6$[8,9]. When compared with the value described above, it is evident that coke has a complicated internal structure and presents a noticeable fluctuation, even if macroscopic cracks are excluded. For these reasons, it is problematic whether or not the fracture theory which has been applied to porous materials is applicable to coke. With this problem left to the future study, the following discussion was advanced on the assumption that coke was statistically homogeneous.

For the sake of easy analysis, a two-phase dispersed system consisting of dispersant and dispersoid is often adopted as a model of porous object. In the case of coke, the two phases correspond to pore walls (dispersoid) and pores (dispersant). In the present study comparing DQ coke with WQ coke, as the quality of coking coal and the carbonizing conditions are identical in both types of coke, the physical properties of dispersoid may be regarded as the same. The porosity, one of important parameters of dispersant, may also be considered identical, as described above. After checking various factors in this way, it may be concluded that the difference in fracture strength between two types of coke is attributable to the difference in the structural sensitivity based on the minute defect structures affecting the development and growth of cracks[10].

A number of empirical formulas have been proposed with regard to the dependency of fracture strength on porosity. In the following analysis, Ryshkewich's formula **(5)** which is said to have wider coverage is adopted[11].

Table 3 Calculated values obtained by eq. (5)

Sample	S_h(kgf/cm²)	ϕ_m(%)	α	Correlation coefficient r
DQ coke	1470	50.6	5.8	0.62**(n=244)
WQ coke	1490	50.5	6.2	0.65**(n=221)

S_h : A hypothetical strength on the assumption of ϕ=0
ϕ_m : Mean value of porosity ϕ
α : An empirical constant (In this analysis, it is assumed that α shows the microstructural features which acts as the Griffith flaws because the ϕ_m of two coke is same)

$$S = S_h \cdot \exp(-\alpha \cdot \phi) \quad \cdots\cdots (5)$$

Where S_h is hypothetical matrix strength with porosity (ϕ) assumed to be zero ($\phi = 0$), that is, strength of dispersoid and α is a constant. The results of calculation based on the logarithmic expression of eq. (5), $\ln S = \ln S_h - \alpha\phi$, are shown in Table 3. According to the statistical analysis, the difference in average porosity between two types of coke was not significant, while that in α-value was significant at the level 10%. Since there is no difference in the porosity between both types of coke, α may serve as a measure of structural sensitivity which affects the strength of coke matrix. It is possible to quantitize the minute structural defects in terms of porosity based on the empirical formula. According to the calculation, it is estimated that coke of 50% mean porosity obtained by the conventional wet quenching process can be improved by dry slow-cooling to the strength level corresponding to WQ coke of 47.5% mean porosity, that is, the CDQ allows the reduction of the porosity by 2.5% in terms of strength.

With regard to brittle fracture, Griffith claims that the strength is reduced when the structural defects such as micro-cracks existing within the material act as the centers of stress concentration. The fracture strength σ is represented by eq. (6)[12] when crack with length of $2C$ exists.

$$\sigma \simeq \sqrt{\gamma \cdot E/C} \quad \cdots\cdots (6)$$

γ: Surface energy
E: Young's modulus

Since two types of coke have identical dispersoid strength S_h (see Table 3), physical properties such as γ and E are the same. The estimation of relative crack size based on a rough approximation regarding σ as mean tensile strength revealed that the CDQ reduces the micro-crack size by about 15% on average in comparison with wet quenching.

The validity of quantitization of minute structural defects described above is to be verified by future studies. Anyway, it is evident that the structural defects can be reduced by the dry slow-cooling.

3.3 Evaluation of Lump Coke Cracks through Static Loading Test with Irregular-shaped Lump Specimens

In the preceding subsection, DQ and WQ cokes were compared with respect to micro-cracks. While it has not yet been elucidated what factor of coke strength is responsible for the fitness to blast furnace operation, it is generally recognized that the conventional index evaluated by the revolution strength is determined by macroscopic cracks. This subsection studied the effect of dry slow-cooling on coke strength by performing a static loading test with lump coke containing structural defects such as macro-cracks.

According to the weakest link hypothesis, the fracture of specimen is determined by the fracture strength of the least resistive parts. The fracture strength distribution of macroscopic specimens composed of many structural elements, therefore, is represented by the distribution of least strength. Since the larger the coke lumps, the greater the number of potential crack-causing fracture, the fracture strength tends to be lower relatively. That is, the fracture strength in the static loading test is related to the specimen volume, and hence, it is necessary to compare two types of coke in terms of each lump sizes. The volume dependency of specimen of strength S is represented in accordance with Weibull by eq. (7) with volume V. Weibull's homogeneity coefficient m can be evaluated on the basis of volume dependency.

$$S \propto V^{-1/m} \quad \cdots\cdots (7)$$

For the details of the theory, see references[13,14]. In the following discussion, the above concept was applied to coke.

3.3.1 Tensile strength of sieved lump coke specimens

In Fig. 11, the tensile strength of lump coke is plotted against the specimen volume. For the sake

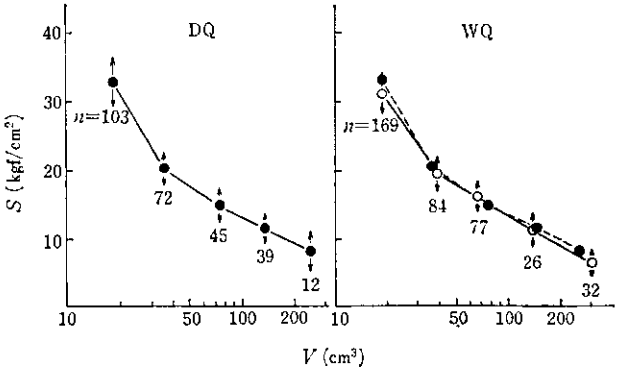


Fig. 11 Relation between tensile strength, S, and volume, V, of lump coke

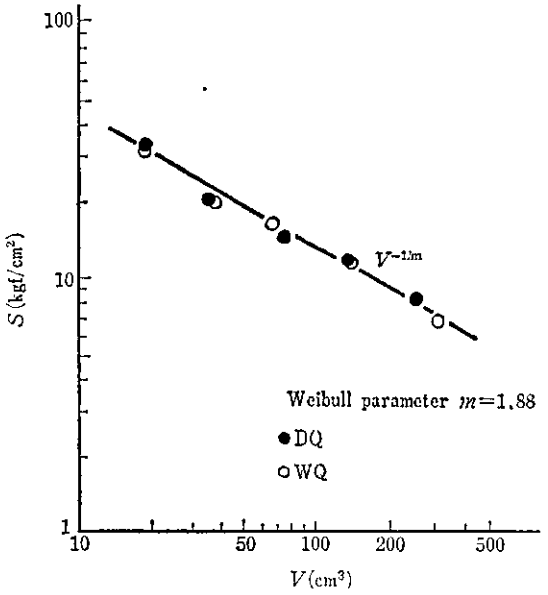


Fig. 12 Volume dependency of tensile strength of lump coke ($S \propto V^{-1/m}$)

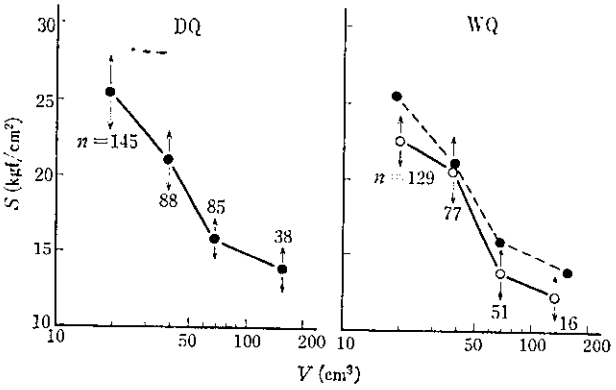


Fig. 13 Tensile strength of lump coke after drum test

of convenience, the abscissa is given in logarithmic scale. Arrows represent interval estimation for confidence limit of 95% probability, with the number of specimens, n, written in the figure. For both types of coke, the greater the lump size, the lower the fracture strength. The statistical analysis revealed that a significant difference existed at the level 5% in the small-sized coke group of average volume 20 cm^3, while the difference in other groups was insignificant. Plotting of S against V in bi-logarithmic representation gave the linear relationship, as shown in **Fig. 12**. Points for two types of coke fell on the same straight line, and m was calculated from the gradient of this line as 1.88, which was smaller than that obtained in the preceding subsection. It was eventually found that coke lump having macroscopic structural defects was very inhomogeneous porous objects.

3.3.2 Tensile strength of lump coke after revolving drum test

Figure 13 shows the results of static loading test using specimens subjected to the drum revolving drum test (150 revolutions) described in 3.1. The strength of DQ coke was higher than that of WQ coke in every volume group. The m-value calculated in the same way as in the preceding subsection was 3.26 and 2.80 for DQ and WQ cokes, respectively.

When comparing the results shown in **Fig. 11**, it was revealed that the strength of both types of coke was low and there was appreciable difference in strength. The fall in the fracture strength was ascribed to the generation of internal cracks (to be called as Griffith crack hereinafter) in lump coke under impacts in the drum revolution testing machine, which causes the fracture. Accordingly, the difference in strength between the two types of coke represents that in impact resistance. It was demonstrated that the so-called improvement of coke strength by stabilization was not related to the substantial improvement of matrix strength, but rather lowered the fracture strength (increasing structural defects), though open cracks might be stablized.

The m-value was greater than that of specimens before the drum test. This may be attributed to the elimination of macroscopic open cracks, which causes the fluctuation in fracture strength, through the revolution impact. The greater m-value in DQ coke is supposedly due to the improbability of occurrence of the macroscopic Griffith cracks because of high impact resistance, as will be described later.

3.3.3 Difference in strength between DQ and WQ cokes in view of static loading test with lump coke

On the basis of the results of the static loading test, the following conclusion may be derived with respect to the difference in strength between two types of coke. Except for larger open cracks in large-sized coke lumps which could not be measured for the present experiment, there was no appreciable difference between two types of coke with respect to quantity and distribution of macroscopic Griffith cracks affecting the fracture strength. However, once impact was applied to coke, a difference would occur in quantity and distribution of macroscopic structural defects between two types of coke. This phenomenon seemed to be attributable to the transition of microscopic Griffith cracks, minute structural defects, into macroscopic Griffith cracks, which occurred more frequently in WQ coke having more minute structural defects. That is, DQ coke has the matrix structure

having greater impact resistance than WQ coke, and dry slow-cooling causes substantial improvement of strength in the coke structure.

3.4 Relationship between Static Load Strength and Revolution Strength

In the present study, it was attempted to grasp the difference in strength between DQ coke and WQ coke from the viewpoint of fragile materials. This method concerns the static fracture probability based on the weakest link theory, dealing only with the static fracture strength which is affected by the distribution of structural defects such as Griffith cracks. The conventional revolution strength involves dynamic factors, and in order to grasp it from the standpoint of materials mechanics, it is necessary to take into consideration the temporal (dynamic) factors such as a rate of crack initiation and crack propagation. It is not always appropriate, therefore, to seek the correspondence between the two factors in terms of the data of the present study. Though the present experiment concerned only one of factors affecting the revolution strength, some discussions will be presented to find the relationship between them.

While the mechanism of coke fracture in the JIS drum testing machine has not yet been clarified fully, it is said that the fracture by impact predominates in this test in comparison with other revolution strength test[15]. The fracture strength shown in **Fig. 13** may be regarded as containing dynamic strength to some extent under the impact hysteresis. In **Fig. 14**, K-values (harmonic average) shown in **Fig. 6** are plotted against tensile strength S of lump coke of **Fig. 13**, showing a relatively distinct correspondence. While the results were obtained within a limited range of specimens, it seems to suggest the direction of future study for elucidating the nature of coke strength.

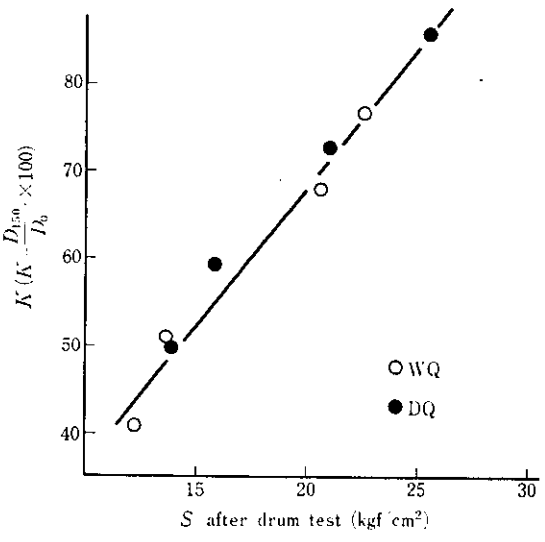


Fig. 14 Relation between K-value at drum test and tensile strength, S, of lump coke after 150 revolution

3.5 Factors for Improving Strength of Dry Quenched Coke

With regard to factors for improving the strength of dry quenched coke, there is a report on the results of drum test[1]. According to this report, the thermal effect of the dry slow-cooling is large in DI_{50}^{150} representing the crushability, and it is concluded that the main factor for improving DI_{15}^{150} which is known to be extensively attributable to the abrasion strength is mechanical hysteresis effect (stabilizing effect). As reported in a trial calculation[16] indicating that cracks due to thermal stress caused by temperature difference between the surface and the interior of lump coke develop in lumps greater than 68 mm in case of wet quenching, and greater than 91 mm in case of dry quenching, it may be presumed that dry quenching is effective for suppressing the occurrence of open cracks determining the crushability. It is considered, however, that some of larger cracks is stabilized in the process

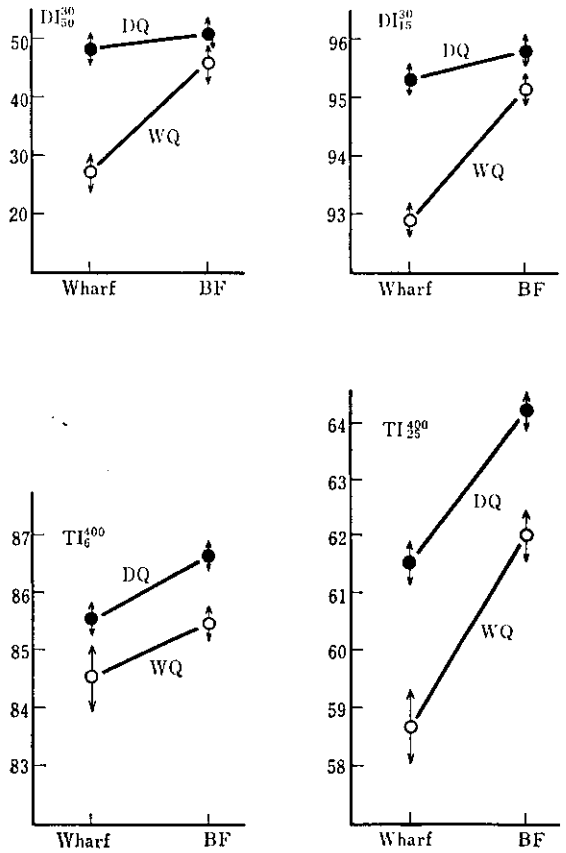


Fig. 15 Changes of coke strength while carrying from wharf to blast furnace

of coke transfer from the wharf to the blast furnace as shown in an example of drum index in **Fig. 15** and contributes little to the substantial improvement of strength. It is thought rather that the essential factor for the quality improvement by dry quenching is the decrease of microscopic Griffith cracks, as pointed out in this paper, and that while some of the cracks are stabilized in the process of coke transfer from the wharf to the blast furnace, as is evident in the example of tumbler index in **Fig. 15**, they constitute the cause for keeping the difference in strength between two types of coke. As for the particle size decreasing by thermal shock, which is generally known as a cause for the degradation of coke in the blast furnace, it is supposed that the quality is improved by the decrease of minute structural defects in DQ coke.

4 Conclusions

(1) The CDQ is effective for reducing microscopic structural defects in coke matrix.

(2) The effect described above suppresses the occurrence of macroscopic cracks caused by impact and contributes to the improvement of DQ coke strength. That is, it may be claimed that DQ coke exceeds WQ coke in matrix structure of greater impact resistance.

(3) The CDQ is highly effective for improving the abrasion resistance of coke.

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