A Fundamental Study on the Dissolution Rate of Solid Lime into Liquid Slag*

By Masaaki MATSUSHIMA,** Shigeyuki YADOOMARU,** Katsumi MORI*** and Yasuji KAWAI***

Synopsis

The rate of dissolution of solid lime into liquid slag was determined from the decrease of diameter of the lime cylinder rotated in CaO-SiO$_2$-Al$_2$O$_3$ or FeO-CaO-SiO$_2$ slag. The penetration of the slag to the solid phase and the distribution of components in liquid slag adjacent into the solid-liquid interface were examined by the E.P.M.A. technique.

The rate of dissolution increased with temperature and with rotating speed of the cylinder, supporting the assumption that the diffusion of calcium through a slag phase boundary layer would be the rate-determining step.

The dissolution rate into the slag containing FeO was several times greater than that into slag without FeO, because of the differences in physical properties of slag and in the morphology of 2CaO-SiO$_2$ formation. Slag components penetrated into solid lime were mainly Al$_2$O$_3$ and FeO, and the SiO$_2$ content was very little. This can be interpreted by the formation of Al$_2$O$_3$ or FeO rich slag layer between solid lime and 2CaO-SiO$_2$ film.

I. Introduction

It is well known that the progress of slag-metal reactions in basic oxygen and electric furnaces is largely influenced by the lime content, and accordingly by the dissolution rate of solid lime into slag. Also, it is supposed that this dissolution rate would have influences on the blast furnace conditions and its productivity. Thus, the dissolution of solid lime into slag plays an important role in iron- and steelmaking practices. Thus, many fundamental and practical investigations have been made on the mechanism and the kinetics of this process and the effect of addition of fluxes. According to the investigations, when a lime dissolves into slag containing SiO$_2$, a film of dicalcium silicate, 2CaO-SiO$_2$, is formed on the lime surface and further dissolution is retarded. The morphology of this silicate film depends on slag composition. For example, a dense film is formed in slags of less than 20%FeO, which prevents the dissolution of solid lime, but a film is discontinuous in slags of more than 20%FeO which has small preventing effect on the dissolution rate. Moreover, physical properties of the solid lime change the rate. Namely, it has been found that a soft-burnt porous lime is favorable for the slag penetration and disintegration, resulting in high dissolution rate into slag.

Most of the previous investigations have been made in a stationary liquid slag. However, the influence of silicate film on the dissolution rate would be different in a stirred slag bath. Only a few investigators reported on this point, but their results on the rate were rather qualitative. In the present work, the dissolution rates of solid lime into stirred slag bath were quantitatively measured. The effects of slag composition and temperature on the rate were also comprehensively investigated. Further, the penetration of slag into solid lime and formation of 2CaO-SiO$_2$ were examined.

II. Experimental Method

1. Experimental Procedure

The experimental apparatus is schematically shown in Fig. 1. 400 g of a slag was melted in a graphite (or iron) crucible of 45 mm inner diameter and 100 mm length under argon atmosphere, using a Tamman furnace. The diameter of the cylindrical lime specimen was about 19.4 mm after sintering. Temperature was measured by a Pt-6%Rh/Pt-30%Rh thermocouple inserted between the heater and the crucible, and near the middle height of slag bath. The temperature was held constant within $5^\circ$C by a controller. Only the side wall of the cylindrical specimen was exposed to slag with the constant length of about 20 mm; both ends of the specimen were covered with graphite (or iron) caps. A vertical hole was made at the center of the cylinder of lime and the rotating rod of Mo (or iron) was inserted to this hole.

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together with the graphite covers to fix the specimen tightly. This assembly was then connected with the axis of a motor through a connecting rod.

The specimen which was sufficiently preheated and rotated at determined rotating speed was slowly dipped into slag. After dipping for the desired time, it was taken up from slag, rotated for a few minutes and cooled slowly. By this procedure, slag sticking to a specimen was taken off very well. Diameters of specimen were measured at several arbitrary points cooled slowly. By this procedure, slag sticking to a specimen was taken off very well. Diameters of specimen were measured at several arbitrary points cooled slowly. By this procedure, slag sticking to a tightly. This assembly was then connected with the slag-solid lime interface was examined by the electron-probe microanalysis or chemical analysis.

2. Preparation of Cylindrical Lime Specimen

20 g of lime powder (−48 mesh) containing a small amount of calcium stearate was pressed into a cylindrical shape of 20 mm diameter and 30 mm length under maximum load of 2 t. This was placed on a magnesia plate in a SiC resistance furnace and was heated up to 1 600°C. The sintering time above 1 500°C was 90 to 100 min. Bulk density and porosity of sintered lime were 1.9 to 2.0 and about 40%, respectively.

3. Preparation of Slag Samples

Slags used for experiments are three kinds of CaO–SiO₂–Al₂O₃ ternary slags and four kinds of FeO–CaO–SiO₂ ternary slags, charge composition of which are listed in Table 1.

The blast furnace (BF) type slags were prepared by melting mixtures of CaO, SiO₂, and Al₂O₃ reagents in a graphite crucible and quenching it on an iron plate. The basic-oxygen-furnace (BOF) type slags were prepared from mixtures of CaO, SiO₂ and FeO powders. FeO was prepared by heating and melting ferrous oxide in an iron crucible in the stream of argon and quenching it on an iron plate. The slags with FeO contained a small amount of ferric oxide and thus the final compositions differed slightly from the charge compositions.

III. Experimental Results

In the case of BF type slags, the effects of revolution speed and temperature on the dissolution rate were examined with slag A. The range of revolution speed was from 200 to 1 000 rpm at temperatures from 1 450° to 1 600°C. The effect of slag composition on the rate was studied at 1 500°C and a revolution speed of 600 rpm. While in the case of BOF type slags, the effects of revolution speed and slag composition on the rate could be examined only at 1 400°C, because of experimental limitation by using iron crucibles.

The results obtained are shown in Figs. 2 to 6 as plots of the decrease of radius of lime cylinder against dipping time. Each experimental point in the figures is the mean value of measurements at several points of the lime cylinder. The dissolution of solid lime proceeded so uniformly over the whole surface that the difference in radius with measuring points was within 0.1 mm.

It can be clearly found from Figs. 2 to 6 that linear relationships hold for all runs. Thus, the dissolution rates can be defined as the slopes of these straight lines. Some of lines do not pass through the origin. This may be attributed to the delay of initial dissolu-

Table 1. Composition of slags

<table>
<thead>
<tr>
<th>Slag</th>
<th>FeO (%)</th>
<th>CaO (%)</th>
<th>SiO₂ (%)</th>
<th>Al₂O₃ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>40</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>40</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>40</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>30</td>
<td>35</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 2. Effect of revolution speed on the dissolution rate of CaO into slag A](image)

![Fig. 3. Effect of temperature on the dissolution rate of CaO into slag A](image)
IV. Discussion on the Dissolution Rate

The dissolution rate of a rotating lime cylinder into molten slag have been investigated by Scheel and Oeters\(^5,8\) and Masui and Yamada.\(^{10}\) Rather low revolution speeds were employed and the dissolution rate was determined by the change of slag composition or weight of specimen. However, their results seem rather qualitative and thus the rate equation was not given. However, the present work gives the rate equation and the rate-determining step as follows.

1. Rate Equation and Rate-determining Step

It is known that most of dissolution processes of solid into liquid are controlled by mass transfer step and its dissolution rate is proportional to the \(n\)-th power of a defined stirring speed, where \(n\) is 2/3 to 4/5.\(^{12}\) In Fig. 7, logarithms of the dissolution rate are plotted against logarithms of the periphery velocity of rotating cylinder, \(U (= \pi d m / 60, d: \text{mean diameter of lime cylinder, } m: \text{number of revolution per minute})\). The lines in this figure can be expressed by the following equations:

For BF type slag (slag A)

\[
- \frac{dr}{dt} = A_0 \cdot U^{0.62}
\]

(1)

For BOF type slag (slag D)

\[
- \frac{dr}{dt} = A_0 \cdot U^{0.69}
\]

(2)

where, \(A_0\) is constant.

These results support the assumption that the dissolution rate of solid lime into molten slag is controlled by the diffusion of calcium through the liquid boundary layer.

Then, the dissolution rate can be expressed by Eq. (3).

\[
v = k(n_v - n_0)
\]

(3)

where, 

- \(v\): the rate of dissolution
- \(k\): mass transfer coefficient (cm/sec)
\( n_2, n_b \): lime contents of slags at the interface and in the bulk, respectively (g/cm\(^3\)).

Since \( v = -\frac{\rho d r}{d t} \) according to the mass balance of lime \((\rho \text{ is bulk density of lime specimen}), Eq. (3) may be rewritten as follows:

\[
-\frac{d r}{d t} = \frac{k}{100\rho} \left[ (\% \text{CaO})_b - (\% \text{CaO})_a \right]
\]

\[\approx \frac{k n_b}{100\rho} \cdot J(\% \text{CaO}) \quad \text{...(4)}\]

\( n_a, n_b \) are densities of slags at the interface and in the bulk, respectively.

Mass transfer coefficients in slag A at 1500°C and in slag D at 1400°C were calculated by Eq. (4) and listed together with the experimental conditions in Table 2. In the calculation, \( J(\% \text{CaO}) \), the driving force of diffusion, was assumed to be equal to the difference between the content of lime in the bulk slag and its solubility in the slag. The latter corresponds to the lime content at the interface of liquid line with a straight line connecting the point of bulk slag composition with the lime corner on the ternary diagram.

Table 2 shows that the mass transfer coefficient increases with increase of revolution speed and values for BOF type slag are about three times larger than those for BF type slag in spite of the lower experimental temperature.

The boundary layer thickness \( \tilde{a} (=D/k) \) can be estimated from the mass transfer coefficient and the diffusivity of lime of \( 5.5 \times 10^{-6} \text{ cm}^2/\text{sec} \) by Johnston, et al.\(^{13} \) and \( 2.7 \times 10^{-5} \text{ cm}^2/\text{sec} \) in FeO-35%SiO\(_2\) slag by Ogino, et al.\(^{14} \) in slag A and slag D, respectively. The larger thickness for slag D than that for slag A, as shown in Table 2, seems to be inconsistent with the viscosity data of the slags. However, this may be due to the inaccuracy of diffusivity values.

On the other hand, the boundary layer thickness can be estimated from the equation obtained by the method of dimensional analysis.

For example, for the dissolution of a rotating benzoic acid cylinder into water,\(^{19} \) the thickness was empirically expressed by

\[ \tilde{a} = 12.6 \cdot d \cdot \text{Re}^{-0.7} \cdot \text{Sc}^{-0.336} \quad \text{...(5)} \]

and for the dissolution of a rotating steel bar into liquid zinc or aluminum at high temperature,\(^{20} \)

\[ \tilde{a} = 4.76 \cdot d^{1.4} \cdot \text{Re}^{-0.62} \cdot \text{Sc}^{-0.8} \quad \text{...(6)} \]

where, \( d \): diameter of rotating bar

\( \text{Re} \): Reynolds number \((=\rho \cdot d \cdot U/\eta)\)

\( \text{Sc} \): Schmidt number \((=\eta/\rho \cdot D)\).

Values of boundary layer thickness calculated from Eq. (6) are also given in Table 2. Values of physical properties used in the calculation are listed in Table 3. The comparison of boundary layer thicknesses calculated from Eq. (6) with those from \( k \) shows a little difference for runs with slag A, but a fairly good agreement for runs with slag D. There are some problems on values of physical properties of slags used for the calculations. However, these results support that the rate-determining step is the mass transfer through a slag phase boundary layer.

2. \( J \)-factor for Mass Transfer

In the field of chemical engineering the dimensional analysis is widely applied to analyze many problems of heat and mass transfer. The following relation has been empirically obtained for the \( J \)-factor concerning the mass transfer from a solid plate or cylinder to liquid under forced convection:\(^{21} \)

\[ J = \text{St} \cdot \text{Sc}^a = \text{const} \times \text{Re}^b \quad \text{...(7)} \]

where, \( \text{St} \): Stanton number \((=k/U)\)

\( a \) and \( b \): constant and \( a \) is considered to be \( 1/3 \) to \( 2/3 \).

For the case where a plate or cylinder of salt and benzoic acid dissolve into water and organic liquid the following equations are derived experimentally:

for laminar flow \[ J = 0.664 \text{Re}^{-0.5} \quad \text{...(8)} \]

for turbulent flow \[ J = 0.037 \text{Re}^{-0.2} \quad \text{...(9)} \]

In addition, for the dissolution of rotating metal cylinder into liquid metal (steel-Al, steel-Zn and Cu-Pb) the \( J \)-factor was expressed as follows:\(^{22} \)

\[ J = (k/U) \cdot \text{Sc}^{2/3} = 0.065 \text{Re}^{-0.25} \]

\[ 2 \times 10^2 < \text{Re} < 1 \times 10^4 \quad \text{...(10)} \]

The \( J \)-factor for the present results were also calculated on the assumption that \( a \) is \( 2/3 \), similarly to the previous works and the following relations were obtained:

for runs with slag A at 1500°C

Table 3. Physical properties of slag

<table>
<thead>
<tr>
<th>Slag</th>
<th>Temp. (°C)</th>
<th>( \rho_b ) (g/cm(^3))</th>
<th>( D_{\text{CN}} ) (cm(^2)/sec)</th>
<th>( \eta ) (poise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1500</td>
<td>2.79 (^{19})</td>
<td>5.5 \times 10^{-6} (^{15})</td>
<td>9.2 (^{17})</td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td>2.79 (^{19})</td>
<td>5.5 \times 10^{-6} (^{15})</td>
<td>9.2 (^{17})</td>
</tr>
<tr>
<td>D</td>
<td>1400</td>
<td>3.15 (^{14})</td>
<td>2.7 \times 10^{-5} (^{16})</td>
<td>1.7 (^{18})</td>
</tr>
<tr>
<td></td>
<td>1400</td>
<td>3.15 (^{14})</td>
<td>2.7 \times 10^{-5} (^{16})</td>
<td>1.7 (^{18})</td>
</tr>
</tbody>
</table>
J = 0.495 \cdot \text{Re}^{-0.34} \quad \text{.....}(11)

for runs with slag D at 1400°C

J = 0.384 \cdot \text{Re}^{-0.31} \quad \text{.....}(12)

These relations are shown in Fig. 8, in which only a little difference between two lines is found in spite of different slag systems. The present results can be considered reasonable, referring to Eq. (8) or (10) and one of evidences showing that the line dissolution is a diffusion-controlled reaction.

3. **Effect of Temperature on the Dissolution Rate**

The effect of temperature on the dissolution rate was investigated on slag A at a revolution speed of 600 rpm. The results obtained have been already shown in Fig. 3. Mass transfer coefficients calculated by Eq. (4) are given in Table 4.

Figure 9 shows a plot of logarithm of $k$ against $1/T$. A linear relationship holds within the experimental range. The apparent activation energy can be calculated from the slope to be 63.5 kcal/mol.

Rewriting Eq. (7) for the $J$-factor,

$$k = \text{const.} \cdot (\gamma / \rho D)^{-a} (\mathbf{D}U / \gamma)^b \quad \text{.....}(13)$$

and at constant revolution speed, this can be simplified as follows:

$$k = \text{const.} \cdot (\gamma / \rho)^{-a} \cdot \mathbf{D}^b \quad \text{.....}(14)$$

Neglecting the temperature dependence of slag density and taking logarithms of both sides of Eq. (14), one has

$$\log k = \text{const.} - (a + b) \log \gamma - a \cdot \log \mathbf{D} \quad \text{.....}(15)$$

This equation tells us that the activation energy for mass transfer can be estimated from those for viscous flow of slag, $E_a$, and for diffusivity in slag, $E_D$. Assuming that $a = 2/3$ and $b = -0.34$ from Eq. (11), and $E_a$ and $E_D$ are about 50 and 70 kcal/mol, respectively, the activation energy calculated from Eq. (15) is about 64 kcal/mol, which is in a good agreement with the experimental value.

It may be also predicted from Eq. (15) that the effect of temperature may be smaller for BOF type slags than for BF type slags.

4. **Effect of Slag Composition on the Dissolution Rate**

Increases of the dissolution rate with decrease of CaO content in slag and with increase of FeO content are seen in Figs. 4 and 6. As seen from Eq. (4), the dissolution rates would be determined by the viscosity of slag, diffusivity coefficient in slag, stirring speed and concentration difference of CaO as driving force. Table 5 summarizes the dissolution rates, mass transfer coefficients obtained from Figs. 4 and 6 and the concentration differences.

Mass transfer coefficients for BF type slags are nearly equal. Hence, the larger dissolution rate into slag C may be due to the larger concentration difference. On the other hand, the dissolution rates into BOF type slags are nearly proportional to the values of mass transfer coefficients. The low dissolution rate into slag E, in spite of the large concentration difference, may be attributed to the small mass transfer coefficient due to its large viscosity and thick boundary layer.

V. **Penetration of Slag into Solid Lime**

After dipping experiments, a concentric reacted zone was observed on the transverse section of the lime. This zone seemed to be produced by the pene-

![Fig. 9. Effect of temperature on the mass transfer coefficient in slag A](image)

Table 5. Dissolution rate and mass transfer coefficient

<table>
<thead>
<tr>
<th>Slag</th>
<th>$-\frac{dr}{dt}$ (cm/sec)</th>
<th>$k$ (cm/sec)</th>
<th>$J$(%CaO)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$9.7 \times 10^{-4}$</td>
<td>$5.9 \times 10^{-4}$</td>
<td>9.5</td>
<td>CaO</td>
</tr>
<tr>
<td>B</td>
<td>$6.8 \times 10^{-4}$</td>
<td>$7.5 \times 10^{-4}$</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>$1.7 \times 10^{-4}$</td>
<td>$6.7 \times 10^{-4}$</td>
<td>20.5</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>$6.5 \times 10^{-4}$</td>
<td>$9.7 \times 10^{-4}$</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>$2.3 \times 10^{-4}$</td>
<td>$1.0 \times 10^{-3}$</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>$2.4 \times 10^{-4}$</td>
<td>$3.0 \times 10^{-3}$</td>
<td>4.7</td>
<td>600 rpm</td>
</tr>
<tr>
<td>G</td>
<td>$3.0 \times 10^{-4}$</td>
<td>$4.0 \times 10^{-3}$</td>
<td>4.4</td>
<td>1500°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200 rpm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1400°C</td>
</tr>
</tbody>
</table>
tration of slag. The boundary between the reacted and unreacted zones was not clear for runs with BF type slags but distinctly recognized for runs with BOF type slags by the coloration of the reacted zone. Moreover, the existence of heterogeneous parts was observed in the reacted zone by the microscopic examination.

The formation of $2CaO\cdot SiO_2$ in the reacted zone for slag A was confirmed by X-ray diffraction analysis, though its amount was very small. It was found that the weight ratio of Al/Si in this layer was 0.9 to 3.6 (mean 1.6) according to the electron-probe microanalysis. Besides, the chemical analysis of the reacted layer showed $Al_2O_3$ of 4 to 6% and $SiO_2$ of 2 to 3%, and thus, $(%Al_2O_3)/(%SiO_2)=1.6~2.1$, which was large compared with 0.5 for bulk slag. These data show the more penetration of Al$_2$O$_3$ than SiO$_2$ into a solid lime specimen.

The chemical analysis of the reacted zone by slag D showed that FeO content in this layer was about 10% and SiO$_2$ only a little. Also, from the electron-probe microanalysis, the same result was obtained. Thus, it was clear that the penetrated slag was different in the composition from the bulk slag in both cases of BF and BOF type slags. These phenomena would be related to the dissolution mechanism of solid lime into slag as discussed in the following section.

VI. Mechanism of Dissolution of Solid Lime

The mechanism of dissolution of solid lime into slag has been investigated by many workers, especially on slags containing FeO by Hachtel, et al. and Oeters and Scheel and on slags containing Al$_2$O$_3$ by Kimura, et al. According to those results, when a solid lime was dipped into static slags, solid solution, (Ca, Fe)$_2$O$_3$, and 2CaO-SiO$_2$ or 3CaO-SiO$_2$ were formed on its surface. If a lime specimen is porous, slag components simultaneously penetrate into the pore. Thereafter, the counter diffusions of calcium from the interface and of silicon from the bulk slag lead to the formation of 2CaO-SiO$_2$ film at places somewhat apart from the interface. The concentration profile of slag components in such a case may be schematically shown as Fig. 10. The mode of the film formation and its growth has a large influence on the subsequent dissolution of solid lime.

It is known that the films formed in slags of high FeO and low SiO$_2$ contents are discontinuous and have a small retarding effect on the dissolution of the lime, whereas the dense films are formed continuously in slags of low FeO and high SiO$_2$ contents, and would retard the rate markedly. This mode of the formation of 2CaO-SiO$_2$ was here studied on a crystal of lime to avoid the complexity due to the porosity of the sintered lime. The reaction time was extended compared with previous works.

A 2 mm square and 5 mm long crystalline lime was dipped into the static slag bath for a time and then rapidly cooled by taking it out from the furnace in order to prevent the transformation of solidified structure. The concentration profile in the vicinity of the interface was measured by the electron-probe microanalysis along with the microscopic examination.

Some examples of the results of the line scanning analysis are shown in Fig. 11 on slag A at 1 500°C and in Fig. 12 on slag G at 1 400°C. It was seen from these figures that the slag adjacent to the solid-slag interface contained higher FeO or Al$_2$O$_3$ content and 2CaO-SiO$_2$ or 3CaO-SiO$_2$ was formed at places slightly and sometimes considerably apart from the interface. The formation of this film was not always observed clearly because of many cracks generated on cooling. In addition, the formed film was discontinuous as seen in Photo. 1. Such an observation on static slag nearly agrees with the previous reports.

The FeO or Al$_2$O$_3$-rich and SiO$_2$-poor slags near the interface indicate that the amount of silicon reached to the interface is small due to the formation of 2CaO-SiO$_2$ film at places slightly apart from the interface, while the transfer of iron or aluminum is hardly affected by this film. As described in the preceding section, low SiO$_2$ content and high Al$_2$O$_3$ or FeO content in the slags penetrated into solid lime may be due to the small amount of silicon reached to the interface.

When a lime specimen was dipped into the slag, (Ca, Fe)$_2$O$_3$ solid solution, 2CaO-SiO$_2$ and 3CaO-SiO$_2$ might be rapidly formed on the specimen surface, even if their amounts were a very little. Thereafter, the dissolution of solid lime might proceed by the
diffusion of calcium through the $\text{Al}_2\text{O}_3$ or FeO-rich slag layers adjacent to the lime specimen and through the $2\text{CaO} \cdot \text{SiO}_2$ or $3\text{CaO} \cdot \text{SiO}_2$ films formed in the vicinity of the interface. It is difficult to determine the rate-controlling step for the initial period of the dissolution process in the slag where the amounts of $2\text{CaO} \cdot \text{SiO}_2$ and $3\text{CaO} \cdot \text{SiO}_2$ films and their distribution are not clearly known. The analysis of rate equation in Section IV for the period of the steady state of the dissolution was carried out on the assumption that the interfacial concentration of CaO was the liquidus concentration on the straight line connecting the bulk slag composition with the CaO corner on the ternary phase diagram. For the latter period, it may be considered that the product on the surface of lime specimen is mainly $2\text{CaO} \cdot \text{SiO}_2$ and the dissolution rate is controlled by the diffusion of calcium from the surface of $2\text{CaO} \cdot \text{SiO}_2$ film. If so, the concentration of CaO at the intersect of liquidus line with a straight line connecting the point of $2\text{CaO} \cdot \text{SiO}_2$ instead of the CaO corner with the bulk slag composition should be used as the interfacial concentration. However, the errors involved in Section IV were so small that the results of analysis in the present work may not differ very much. Furthermore, in stirred slag bath, some of $2\text{CaO} \cdot \text{SiO}_2$ would disperse and dissolve into bulk slag by liquid flow, and would repeat the formation and disappearance. As a whole, the rotating cylinder of lime dissolved under steady state condition during a run.

VII. Conclusion

The dissolution of solid lime into slag was determined from the decrease of diameter of rotating lime cylinder dipped into $\text{CaO} \cdot \text{SiO}_2$-$\text{Al}_2\text{O}_3$ and FeO-$\text{CaO} \cdot \text{SiO}_2$ slags. The penetration of slag into sintered lime and the distribution of slag components in the vicinity of the slag–solid lime interface were also investigated, and then the mechanism on the dissolution of solid lime was considered.

The results obtained are summarized as follows:

1. The dissolution rate increased with revolution speed and with temperature and was in the linear relation with time. Such results can be explained by the rate equation derived on the assumption that the mass transfer step through the slag boundary layer is the rate-determining.

2. The boundary layer thickness and the J-factor were examined in relation to the empirical equation obtained from chemical engineering approach. Also, the activation energy of the dissolving reaction was examined from the activation energies of diffusion and viscous flow. The results of the examination supported that mass transfer is the rate-determining step.

3. The dissolution rate into slags containing FeO was several times greater than that into slags without FeO. This was supposed to be closely related to the difference in the morphology of $2\text{CaO} \cdot \text{SiO}_2$ formation as well as the difference in the physical properties of slag.

4. The concentric penetration of slag components was observed in a sintered lime cylinder. The penetrated slag components were mainly $\text{Al}_2\text{O}_3$ and FeO, while, $\text{SiO}_2$ content was little.

5. The distribution of slag components near the interface and the formation of $2\text{CaO} \cdot \text{SiO}_2$ were investigated by using crystalline lime dipped in the static slag. $2\text{CaO} \cdot \text{SiO}_2$ precipitated at places slightly apart from the interface and the slag near the interface was enriched in $\text{Al}_2\text{O}_3$ or FeO. These results were in a fairly agreement with the previous works.
REFERENCES


