Introduction
Over the past few decades a number of studies have been made with respect to the modeling of cement hydration in order to grasp the time-dependent behavior of cement-based materials[1-3]. In those recent studies, the simulation of intricate and compound processes of cement hydration, especially those focused on micro-mechanics, have utilized the potential of modern computers [4,5]. Two points seem to be helpful in attempting to sketch out what makes it complex to simulate the process of cement hydration and why it needs to be understood using a computer. One is physical aspect. Cement paste matrix, which is composed of cement particles and water is determined by both particle size distribution [1,3] and water-to-cement ratio [7]. In the cement hydration process, cement particles are interconnected and make the structure of the cement paste matrix. This physical aspect affects the rate of cement hydration through the diffusion of ions [3,5]. The second important variable is the poly-mineral material. Its components react with each other, and temperature has a great influence on the rate of hydration from a chemical point of view [2,6]. These two aspects have a mutually dependent relationship through diffusion of ions and water and material formation. This relationship cannot be solved with a simple equation. Using the power of computers, however, and the concept of discrete event system makes it possible to portray the cement hydration process. In this contribution, based on the Tomosawa’s model [8], model for cement paste matrix named ‘CCBM’ [Computational Cement Based Material Model] is proposed and its potential for portraying the concrete properties is discussed with experimental results.

Hydration model
2.1 Background
Proposed hydration model is based on the fundamental kinetic model for Portland cement developed by Tomosawa [8]. Tomoswa’s model, which is originally given in literature [2], is expressed as a single equation (Eq.(1)) composed of four rate determining coefficients which determine the rate of formation and destruction of initial impermeable layer, the activated chemical reaction process and the following relent diffusion controlled process:
\[
\frac{dr}{dt} = \frac{\rho_w C_w}{\gamma_g \rho_c r_i^2} \cdot \frac{1}{k_e r_i^2} + \frac{1}{D_e} + \frac{1}{k_r r_i^2} 
\]

Eq.(1)

where, \( r_i \) is the radius of an unhydrated cement particle (mm), \( R_i \) is the total radius of cement particle including the gel layer (mm), \( D_e \) is the effective diffusion coefficient of water in the cement gel (mm²/h), \( k_e \) is the coefficient of reaction rate per unit area at reaction front (mm/h), \( k_r \) is the coefficient of resistance by protective layer at dormant period (mm/h), \( \gamma_g \) is the stoichiometric ratio by mass of water to cement, \( \rho_c \) is density of cement, \( \rho_w \) is density of water, \( C_w \) is volumetric density of water in cement paste matrix.

This preliminary approach shows high potential of simulating of hydration process. Four coefficients, however, are just fit parameter in Tomosawa’s model and they are not predictable from any information of cement properties. This can be deduced by the fact that the target of modeling of this model is particle hydration process, and not cement paste matrix.

2.2 Assumptions
For the proposed model CCBM, the following assumptions which is originally adopted to Tomosawa’s model and additional changes are adopted:

1. The cement particle initiates hydration from the moment that it is brought into contact with water.
2. The hydrate formed by hydration adheres to the cement particle. And hydrate will be covering it up spherically until interparticle contact comes up. And unhydrated cement keeps spherical shape as well. The new hydrate is formed at the surface with no restriction of interparticle contacts. If the surface contacts with the surface of another particle, new hydrate is no longer produced on it.
3. The hydrate has a \( v \) times as much as the original cement in volume.
4. The liquid phase, which is assumed to be water, diffuses through the hydrate layer and reaches the surface of the cement particle (reacting front) and chemically reacts with cement. This process continues through hydration process. And part of the hydrate produced at the reacting surface moves out through the layer of hydrate. Hence, equimolar counter diffusion of water and hydrate (presumably ions) is assumed to be taking place in the hydrate layer.
5. The diffusion coefficient of hydrate layer for water is not different between outer products and inner products. This diffusion coefficient is affected by tortuosity of gel pore as well as the radius of gel pore in hydrate. This phenomenon can be expressed as a function of degree of hydration.
6. The particle size distribution of cement can be approximated by Rosin-Rammler function. And each particle with the same diameter has the same rate of hydration.
7. Dormant period in the initial process of hydration is assumed that there is a process in which the reaction resistance increases with the increase of degree of hydration in each particle (film formation) followed by a period in which the reaction resistance decreases with increasing thickness of inner products.

2.2 Particle size distribution
Cement particle size distribution will make a big difference in the cement hydration process [9]. When defining the degree of hydration as a ratio of reacted cement volume to initial cement volume, each particle shows a different degree of hydration according to its size when the reaction rate is assumed to be constant among cement particles. Also, the degree of hydration of total cement paste should account for the different degree of hydration of each particle. In the proposed model, it is assumed that the cement particle distribution can be expressed with the Rosin-Ramler Function (Eq.(2)).

\[ V(r_0) = 1 - \exp\left(-b \cdot (2r_0)^n\right) \]  
Eq.(2)

where \( V(r_0) \) is the mass ratio of cement particles smaller than particle with radius \( r_0 \) (g/g) and \( b \) and \( n \) are coefficients for distribution.

2.3 Interparticle contact effect
On the other hand, cement particles develop interparticle contacts as hydration proceeds. After formation of interparticle contact, cement hydration is inhibited by the decrease in area for precipitation of hydrate. It follows from this that the water-to-cement ratio of cement paste is significant for determining the process of cement hydration through geometrical features. In the model proposed here, the cement particles with the radius larger than 1 micro are assumed to be arranged in the cement paste matrix homogeneously as a pseudo-6-neighborhood. The word “pseudo-” is used here in the sense that there exists a particle size distribution and it is possible that neighboring particles are not the same size. Additionally, the particles with the radius less than 1 micro are usually reacts quite rapid and this reaction should not be affected by the reaction of the other particle geometrically. The interparticle contact effect on the rate of hydration of each particle is modeled as the expanding sphere in the unit cubic cell which is determined by the initial water-to-cement ratio. The size of unit cubic cell is defined by Eq.(3).

\[ l = \left(4 \pi \left(\omega \rho_c / \rho_w + 1\right)/3\right)^{1/3} \cdot r_0 \]  
Eq.(3)

where \( l \) is the length of edge of unit cell corresponding to the cement particle with radius \( r_0 \), \( \omega \) is water-to-cement ratio.
The schematic interparticle contact model and the relationship between normalized radius of expanding cement particle \( (R_t/L) \) and its free surface is illustrated in Fig. 1.

![Fig. 1 Schematic of interparticle contact model and free surface area of expanding cement particle as a function of normalized cement radius.](image)

The effect of space limitation on the rate of hydration of cement particle is adopted to Tomosawa’s model as Eq.(4) and Eq.(5):

\[
-\frac{dr_t}{dt} = \frac{\rho_wC_wC_{w0}}{(\gamma_g + \gamma_w)\rho_d r_t^2} \cdot \left[ \frac{1}{k_d r_t^2} \cdot \frac{1}{D_e} \cdot \frac{1}{\frac{1}{R_t} - \frac{1}{R_i}} \right]
\]

Eq.(4)

\[
\frac{dR_t}{dt} = \frac{(v-1) r_t^2}{S(R_t)} \cdot \frac{dr_t}{dt}
\]

Eq.(5)

where \( R_t \) is the radius of cement particle with hydrate, \( \gamma_w (=0.13) \) is the ratio of water adsorbed in gel pore to reacted cement (this is not considered in Tomosawa’s model), \( S(R_t) \) is the function of free surface area on outer products, \( C_w \) is the coefficient for the effect of interparticle contact defined as \( S(R_t)/(4\pi R_t^2) \), \( v \) is assumed to be 2.0, and \( C_w \) represents the free energy of water in the paste matrix and is a function of relative humidity, namely \( C_w = (\rho_h - 0.75)/0.25 \), deduced from experiment by Ono [10].

2.4 Pore structure

Free energy of the adsorbed water in gel pore is affected by the environment such as temperature and relative humidity. And this free energy of the adsorbed water govern the rate of hydration process. Therefore water behavior in cement paste matrix represented by pore size distribution is necessary for modeling the hydration process. In modeling the pore size distribution, a simplified approach of the HYMOISTRUC [5],
based on mercury intrusion, is used in this proposed model. The shape of the pore is assumed cylindrical, and the cumulative pore size distribution for the capillary pore can be described mathematically by the following Eq.(6):

\[ V_{c,\phi} = a \ln(\phi / \phi_0) \]  

where \( V_{c,\phi} \) is the capillary pore volume of all pores with diameter less than \( \phi \), \( \phi \) is diameter of the capillary pore, \( \phi_0 \) is a minimum capillary pore diameter (2nm), and \( a \) is a pore structure constant determined by \( a = V_{\text{pore}} / \ln(\phi_{\text{max}} / \phi_0) \). \( V_{\text{pore}} \) is the total capillary pore volume and, \( \phi_{\text{max}} \) is the maximum capillary pore.

Regarding properties of water such as density, vapor pressure, surface tension and so on have been already modeled by several researchers [11] and their model and following isothermal model [12] is adopted for behavior of water in capillary pore.

\[ l_w = h_0 (\ln(E_{ab} / (RT)) - \ln(-\ln(h))) \]  

where \( l_w \) is thickness of adsorbed water (nm), \( h_0 \) is coefficient (0.194nm), \( E_{ab} \) is an activation energy of adsorption (18kJ/mol), \( R \) is gas constant, and \( T \) is temperature(K).

Given the pore size distribution, amount of capillary water and temperature, Kelvin equation can lead the relative humidity in the pore with Eq. (7), and surface tension and density of water.

2.5 Multi-component concept

Clinker minerals, such as alite(C\textsubscript{3}S), belite(C\textsubscript{2}S), alminate phase(C\textsubscript{3}A), and ferrite phase(C\textsubscript{4}AF) have their own reactions with water. Hence the composition of cement significantly affect on the rate of hydration. Reactions of the individual cement constituents adopted in the proposed model are summarized in Table 1 and density of cement constituents and hydrates are listed in Table 2.

Assuming that nominal reaction rate per unit area of unhydrate cement \( k_r \) can be given by summation of the each reaction rate of cement constituents \( k_{r,i} \), Eq. (14) holds:

\[ k_r = \sum a_i \cdot k_{r,i} \]  

where \( a_i \) is fraction of surface area of each constituents assumed to be equal to volumetric ratio of remained each constituents in unhydrated cement core, and \( i \) represents C\textsubscript{3}S, C\textsubscript{2}S, C\textsubscript{3}A, and C\textsubscript{4}AF.

Consequently, \( \rho_c \) and \( \gamma_g \) are differed during hydration process and are calculated by Eqs. (15) and (16):
\[ \rho_i = \sum a_i \rho_i / \sum a_i \]  
Eq. (15)

\[ \gamma_i = \sum a_i \gamma_i / \sum a_i \]  
Eq. (16)

where \( \rho_i \) is density of each mineral component and \( \gamma_i \) is stoichiometric ratio by mass of water to each constituents determined by the data in Table 1 and Table 2.

**Table 1 Hydration reactions of cement constituents and its heat generation.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Equation</th>
<th>Heat of hydration (J/g)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S</td>
<td>( C_3S + 2.65H \rightarrow C_{1.7}SH_{1.35} + 1.3CH )</td>
<td>519.0</td>
<td>Eq.(8)</td>
</tr>
<tr>
<td>C₂S</td>
<td>( C_2S + 1.65H \rightarrow C_{1.7}SH_{1.35} + 0.3CH )</td>
<td>260.0</td>
<td>Eq.(9)</td>
</tr>
<tr>
<td>C₃A</td>
<td>( C_3A + 3C₅H₈ + 26H \rightarrow C_3A \cdot 3C₅S \cdot H_{32} )</td>
<td>1453.0</td>
<td>Eq.(10)</td>
</tr>
<tr>
<td></td>
<td>( 2C_2A + C_3A \cdot 3C₅S \cdot H_{32} + 4H \rightarrow 3C_3A \cdot C₅S \cdot H_{12} )</td>
<td>996.3</td>
<td>Eq.(11)</td>
</tr>
<tr>
<td>C₄AF</td>
<td>( C_4AF + 3C₅H₂ + 27H \rightarrow C_3(AF) \cdot 3C₅S \cdot H_{32} + CH )</td>
<td>419.0</td>
<td>Eq.(12)</td>
</tr>
<tr>
<td></td>
<td>( \rightarrow 3C_3(AF) \cdot C₅S \cdot H_{12} + 2CH )</td>
<td>276.0</td>
<td>Eq.(13)</td>
</tr>
</tbody>
</table>

**Table 2 Density of chemical components concerning cement hydration system.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Density (g/cm³)</th>
<th>Component</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S</td>
<td>3.15</td>
<td>C₁₇SH₁₃₅</td>
<td>2.60</td>
</tr>
<tr>
<td>C₂S</td>
<td>3.26</td>
<td>CH</td>
<td>2.24</td>
</tr>
<tr>
<td>C₃A</td>
<td>3.04</td>
<td>C₂A \cdot 3C₅S \cdot H_{32}</td>
<td>1.73</td>
</tr>
<tr>
<td>C₄AF</td>
<td>3.77</td>
<td>3C₃A \cdot C₅S \cdot H_{12}</td>
<td>1.99</td>
</tr>
<tr>
<td>C₅H₂</td>
<td>2.32</td>
<td>C₄AF \cdot 3C₅S \cdot H_{12}</td>
<td>1.77</td>
</tr>
<tr>
<td>C₁₇SH₄</td>
<td>2.12</td>
<td>3C₄AF \cdot C₅S \cdot H_{12}</td>
<td>2.08</td>
</tr>
</tbody>
</table>

*1: including physically bound water, *2: excluding physically bound water

2.6 Dormant period
As the mechanism of dormant period of hydration process has not been cleared, the rate determining coefficient \( k_d \) is phenomenologically determined as follows:

\[ k_d = B/\alpha^{1.5} + C(t_0 - t)^{4.0} \]  
Eq.(17)

where \( B \) and \( C \) is rate determining coefficients and \( \alpha \) is averaged degree of hydration of cement.

Eq.(17) reflects experimental results that the dormant period is not affected by the cement particle size and the second peak in calorimeter
test is affected by the cement particle size [13].

2.7 Effect of temperature
The temperature effect on the rate determining coefficients in Eqs.(4) and (17) is modeled with Arrhenyou’s low as follows:

\[ B = B_{293} \cdot \exp\left(-\beta_1 (1/T - 1/293)\right) \quad \text{Eq.}(18) \]
\[ D_e = C_{\alpha,T} \cdot D_{e,293} \cdot \exp\left(-\beta_2 (1/T - 1/293)\right) \quad \text{Eq.}(19) \]
\[ k_{i,j} = k_{i,293} \cdot \exp\left(-E_i / R(1/T - 1/293)\right) \quad \text{Eq.}(20) \]

where \( B_{293}, D_{e,293}, \) and \( k_{i,293} \) are value of \( B, D_e, \) and \( k_{i,j} \) at 293K respectively and \( \beta_1, \beta_2, \) and \( E_i \) are coefficients for temperature dependent of \( B, D_e, \) and \( k_{i,j} \) respectively. \( C_{\alpha,T} \) is a coefficient for taking account of the effect of degree of hydration and curing temperature on \( D_{e,293}. \)

2.8 Structural change of hydrates
Kondo [1] pointed to the effect of the degree of hydration on the hydrate composition, that is C/S ratio increases with increasing degree of hydration. And several papers reported on an effect of the temperature on the composition of the reaction products [14] and C/S ratio is increased when the curing temperature is elevated [15]. These phenomena partially supported the validity that the effective diffusion coefficient of water in the cement gel \( D_e \) is decreased with the increase of degree of hydration and the higher temperature curing, while Tomosawa originally modeled the tendency of decrease in effective diffusion coefficient as a function of degree of hydration [3]. The proposed model CCBM also take into account of these tendencies with phenomenal Eq.(21):

\[ C_{\alpha,T} = (1-\alpha)^2 \left( \frac{0.95}{1 + \exp((T - 333)/2)} + 0.05 \right) \quad \text{Eq.}(21) \]

3. Determination of model parameters
In the foregoing chapters some characteristic model features and the relative influence of several rate determining factors of CCBM were discussed qualitatively. This chapter deals with the quantification of the model parameters of Eqs.(4,5,6,14,17,18,19, and 20).
For determination of model parameters, degree of hydration of cement paste was determined with Rietveld analysis whose accuracy is discussed in ref. [16]. In the experiment, 2 type of cements (NC and LC) with w/c ratio of 0.35 and 0.5 as well as curing condition at 283, 293, and 313 (K) are tested The chemical composition of cements, mineral composition and coefficients for Rosin-Ramler function determined by the particle distribution test with X-ray scattering are summarized in Table 3 and Table 4.
Samples were prepared as follows: Mix the materials at the specified temperature and seal-cure until the specified age. Cut the specimen to an appropriate size with a diamond cutter and finely pulverize with acetone using a disk mill. After separating the powder from acetone by suction filtration, dry the sample for approximately two weeks in an environment of 15%RH, to obtain a hydration analysis sample. The powder X-ray diffraction was measured under the following conditions: The X-ray source: Cu-Kα; tube voltage: 50 kV; tube current: 250 mA; scan field: 2 (theta) = 5 to 65 deg; step interval: 0.02 deg; and scan speed: 2 deg/min. The TOPAS software from Bruker AXS Inc. was used for Rietveld analysis. The subjects of quantification were cement minerals and hydrates, such as C₃S, C₂S, cubic C₃A, orthorhombic C₃A, (total C₃A), C₄AF, MgO, free-CaO, CaCO₃, CaSO₄.2H₂O, CaSO₄.1/2H₂O, Ca(OH)₂ (CH), C₃A.3CaSO₄.32H₂O (AFT), C₃A.CaSO₄.12H₂O (AFm), C₃A.CaCO₃.-12H₂O (monocarbonate), and C₃A.1/2CaCO₃.1/2Ca(OH)₂.12H₂O (hemiacarbonate), as well as a-Al₂O₃ mixed with the analysis samples at 10% by weight as the internal standard.

The parameters for the crystal system, space group, and crystal structure of each mineral were assumed to be the same as those described in reference [17]. All amorphous substances were assumed to be C-S-H in this study and calculated by Eq. (22) from the quantitative value of the internal standard of Al₂O₃ [18].

\[
A = \frac{100(S_r - S)}{S_r (100 - S) / 100}
\]

Eq. (22)

where, \( A \) = proportion of amorphous substance (%), \( S \) = mixing rate of Al₂O₃ (%), \( S_r \) = quantitative value of Al₂O₃ (%)

Table 3 Chemical composition of cement and coefficients for particle size distribution

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>b</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>ig.loss</td>
<td>(%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>2.4</td>
<td>20.2</td>
<td>5.39</td>
<td>3.04</td>
<td>64.6</td>
<td>0.92</td>
<td>1.91</td>
<td>0.30</td>
<td>0.31</td>
<td>0.035</td>
</tr>
<tr>
<td>LC</td>
<td>0.87</td>
<td>26.5</td>
<td>2.65</td>
<td>2.95</td>
<td>63.2</td>
<td>0.72</td>
<td>2.18</td>
<td>0.19</td>
<td>0.34</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Table 4 Mineral composition of cement and other physical properties

<table>
<thead>
<tr>
<th></th>
<th>Density (g/cm³)</th>
<th>Blaine (cm²/g)</th>
<th>Composition by Bogue eq.</th>
<th>Rietveld analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>3.16</td>
<td>3300</td>
<td>63.3 10.3 9.1 9.2 58.6 17.2 7.0 9.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC</td>
<td>3.22</td>
<td>3430</td>
<td>27.3 55.5 2.0 9.0 30.6 54.6 0.8 8.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Experimental results of degree of hydration of each constituents in NC and LC are presented in Fig. 2 and Fig. 3 respectively. In order to satisfy the experimental results, the parameters of CCBM are determined. The lists of parameter values are listed in Table 5.
From the experiment, the following results are obtained. In the higher temperature, namely curing temperature at 313K, the reaction of C\(_3\)A shows sign of leveling off at degree of hydration about 0.7, while in the case of C\(_4\)AF it is about 0.4. After sudden decrease in rate of hydration, they continuing very slow hydration. This phenomena can not be simulated by foregoing theoretical approach, the descriptive models shown as *2 and *3 in Table 5 are adopted to CCBM.

Additionally the rate of hydration of C\(_2\)S has strong connectivity to the degree of hydration of C\(_3\)S. This mutual relationship, which is shown in Fig. 4, is also modeled as phenomenal approach (*1 in Table. 5).

![Fig. 2 Degree of hydration of C\(_3\)S, C\(_2\)S, C\(_3\)A and C\(_4\)AF in NC (marks) by Rietveld analysis and results of simulation by CCBM (lines).](image)

![Fig. 3 Degree of hydration of C\(_3\)S, C\(_2\)S, C\(_3\)A and C\(_4\)AF in LC (marks) by Rietveld analysis and results of simulation by CCBM (lines).](image)
Table 5 Values of model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_i$ (μm/h)</td>
<td>0.07</td>
<td>Eq.(8)</td>
</tr>
<tr>
<td>$\frac{E_i}{R}$ (K)</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>C3S</td>
<td>0.07</td>
<td>6000</td>
</tr>
<tr>
<td>C2S</td>
<td>0.004</td>
<td>3500</td>
</tr>
<tr>
<td>C2S*C2S</td>
<td>3500</td>
<td>Eq.(9)</td>
</tr>
<tr>
<td>C3A</td>
<td>0.01</td>
<td>7000</td>
</tr>
<tr>
<td>0.03</td>
<td>7000</td>
<td>Eq.(11)</td>
</tr>
<tr>
<td>0.001</td>
<td>7000</td>
<td>Eq.(11)</td>
</tr>
<tr>
<td>C4AF</td>
<td>0.01</td>
<td>7000</td>
</tr>
<tr>
<td>0.01</td>
<td>3000</td>
<td>Eq.(13)</td>
</tr>
<tr>
<td>0.001</td>
<td>3000</td>
<td>Eq.(13)</td>
</tr>
</tbody>
</table>

$\alpha_i$ : degree of hydration of each constituents

$^1$ : $\alpha_{C3S}>0.8$ and $C_{C2S}=1.5$

$^2$ : $\alpha_{C3A}>0.7$ and $T>313K$

$^3$ : $P_{C3S}$ is percentage of C3S of cement

Fig. 4 Degree of hydration of C2S as a function of that of C3S

4. Evaluation of model parameters

In order to evaluate the model parameters determined in former chapter, the experimental results for adiabatic temperature rise [6,19] are compared with those CCBM simulation. Getting the adiabatic temperature rise, heat capacity of concrete is assumed that it is equal to the summation of the heat capacity of each component; such as cement hydrate (1.20 Jg⁻¹K⁻¹), unhydrated cement (0.78 Jg⁻¹K⁻¹), water (4.19 Jg⁻¹K⁻¹), sand and aggregate (0.85 Jg⁻¹K⁻¹) [20].

The cement properties and mix proportions of concrete listed in Table 6. And the results of comparison are shown in Fig. 5. As is shown in Fig. 5, CCBM shows high potential for simulating the hydration process, even though the composition of cement is calculated by Bogue equation.

Table 6 Composition by Bogue eq. RR func. Mix Proportion (kg/m³)

<table>
<thead>
<tr>
<th>OPC200</th>
<th>OPC400</th>
<th>LPC300</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3S</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>C2S</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>C3A</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C4AF</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>CSH₂</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>RR</td>
<td>b</td>
<td>0.0303</td>
</tr>
<tr>
<td>func.</td>
<td>n</td>
<td>1.1</td>
</tr>
<tr>
<td>Mix Proportion (kg/m³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>157</td>
<td>157</td>
</tr>
<tr>
<td>C</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>S</td>
<td>862</td>
<td>658</td>
</tr>
<tr>
<td>G</td>
<td>1089</td>
<td>1129</td>
</tr>
</tbody>
</table>
5. Conclusion

A numerical hydration model named CCBM, which take account of particle size distribution, inter-particle contact effect on rate of hydration, mineral composition of cement, and curing condition, is proposed. The parameters of the proposed model are determined from experimental data and those parameters are evaluated by comparison with experimental results of adiabatic temperature rise. The proposed model shows preferable results in several cases, while an applicable scope of this model should be cleared with further evaluation.

References