고칼슘 플라이애시 혼입한 콘크리트의 수화반응 모델에 관한 연구

Hydration modeling of high calcium fly ash blended concrere

번 위 결* 왕 소 용**
Fan, Wei-Jie Wang, Xiao-Yong

Abstract

High-calcium fly ash (FH) is widely used as mineral admixtures in concrete industry. In this paper, a hydration model is proposed to describe the hydration of high-calcium fly ash blended-cement. This model takes into account the hydration reaction of cement, the chemical reaction of fly ash, and reaction of free CaO in fly ash. Using the proposed model, the development of compressive strength of FH blended concrete is predicted using the amount of calcium silicate hydrate (CSH). The agreement between simulation and experimental results proves that the new model is quite effective.

키 워 드 : 고칼슘 플라이애시 . 콘크리트. 수화. 모델
Keywords : high calcium fly ash. Concrete. Hydration. Model

1. Introduction

Mineral admixtures such as silica fume, fly ash, and slag is widely used in concrete. There are two general classes of fly ash can be defined: low-calcium fly ash (FL: CaO content is less than 10%) and high-calcium fly ash (FH: CaO is greater than 10%). Modeling of hydration of cement based materials is very useful to evaluate the age dependent properties of concrete. FH can consume $Ca(OH)_2$ (CH) produced from hydrate (CSH). Using the amount of CSH, the development of the compressive strength can be predicted.

2. Cement-FH blends hydration model

2.1 Model of cement hydration

The basic hydration equation for cement hydration can be described in the following Eq. (1), which was originally created by Tomosawa [1]: This model is expressed as a single equation consisting of three coefficients: k_d the reaction coefficient in the induction period; D_e the effective diffusion coefficient of water through the CSH gel; and k_r a coefficient of the reaction rate of mineral compound of cement as shown in eqs. (1) below:

$$\frac{d\alpha}{dt} = \frac{3C_{W\infty}}{(v+w)r_0\rho_c} \frac{1}{(\frac{1}{k_d} - \frac{r_0}{D_e}) + \frac{r_0}{D_e}(1-\alpha)^{\frac{-1}{3}} + \frac{1}{k_r}(1-\alpha)^{\frac{-2}{3}}} \quad (1)$$

2.2 Model of FH reaction in cement-FH blends

In FH, only glass phase will react, and the hydration equation of the active (glass) part in FH can be written as Eq. (2), diffusion coefficient; $m_{CH}(t)$=calcium hydroxide content; k_{rFH}=reaction rate coefficient.[2-3]

$$\frac{d\alpha_{glass}}{dt} = \frac{3C_{free}\rho_w m_{CH}(t) \times 1/v_{FH} r_{0FH}\rho_{FH} P}{(\frac{1}{k_{dFH}} - \frac{r_{0FH}}{D_{eFH}}) + \frac{r_{0FH}}{D_{eFH}}(1-\alpha_{glass})^{\frac{-1}{3}} + \frac{1}{k_{rFH}}(1-\alpha_{glass})^{\frac{-2}{3}}} \quad (2)$$

* 강원대학교 건축공학과 석사과정
** 강원대학교 건축공학과 조교수, 교신저자(wxbrave@kangwon.ac.kr)

3. Fractions of cement-FH blends

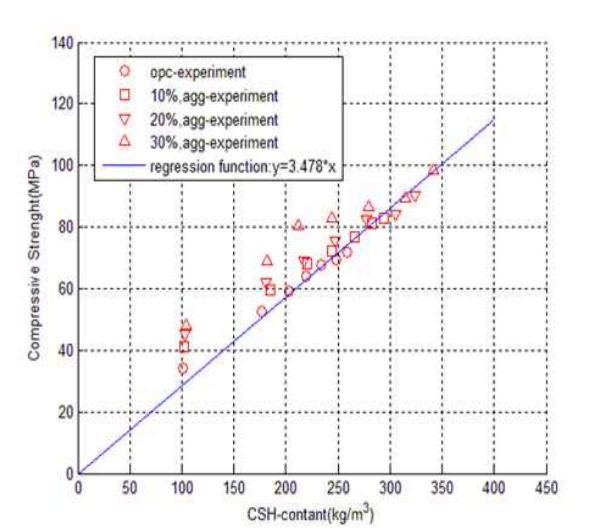
Using the molar weights of reactants and products, the amounts of the produced compounds calcium hydroxide (CH) and calcium silicate hydrate (CSH) can be calculated as Eq. (2-3). The Portland cement and FH can be analyzed in terms of oxides: total CaO (C), SiO_2 (S), Al_2O_3 (A), Fe_2O_3 (F), SO_3 ($\bar{S}$).

$$CH=RCH_{CE}\alpha Ce-\{(1.851\gamma_S f_{S,p}+2.182\gamma_A f_{A,p})-1.321(f_{C,p}-0.7f_{\bar{S},p})\}\alpha_{glass}P \quad (2)$$

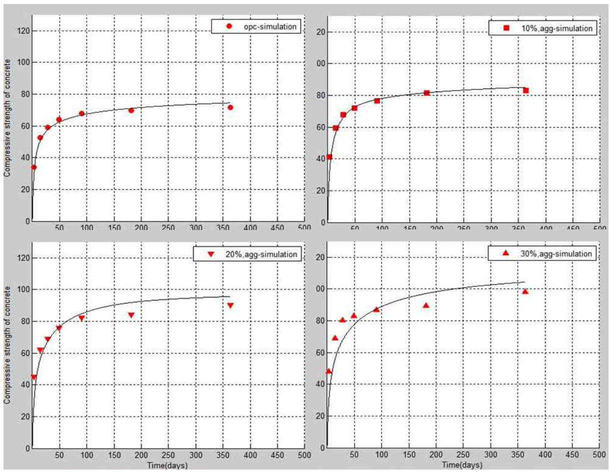
$$CSH=2.85(f_{S,c}\times\alpha\times Ce+\gamma_S f_{S,p}\times\alpha_{glass}\times P) \quad (3)$$

4. The relationship between compressive strengths and calculated CSH amounts

Using proposed hydration model, we can calculate CSH contents. Fig.1 presents the compressive strength of FH blended concrete as a function of calculated CSH contents.



(1-a)comparison between compressive strength & CSH-contant



(1-b)comparison between experiment results & simulation results of compressive strength of mortars.

Figure 1. Compressive strength of concrete as a function of calculated CSH content.

As shown in Fig.(1-a), for concrete with different FH contents and different ages, a single linear relationship exists between the compressive strengths and calculated CSH amounts. Fig.(1-b) shows the comparison between experiment results and simulation results of compressive strength of mortars. We can clearly find that good agreement between predicted value and experimental value.

5. Conclusions

The paper presents a kinetic hydration model of cement-FH blends. The reaction of FH is divided into three processes, i.e. initial dormant process, phase boundary reaction process, and diffusion process. The amounts of calcium silicate hydrate (CSH) are predicted considering the contributions from cement hydration and FH reaction. Furthermore, the development of compressive strength of FH-concrete is evaluated using CSH contents. The simulation results agree with experimental results.

References

1. Tomosawa, F., Development of a Kinetic Model for Hydration of Cement, Proceedings of the 10th International Congress Chemistry of Cement, V. II, F. S. Glasser and H. Justnes, eds., Gothenburg, 1997.8

2. Wang, X.-Y.; Lee, H.-S.; and, Park, K.-B., Simulation of Low-Calcium Fly Ash Blended Cement Hydration, Materials Journal, Volume 106, Issue 2, pp.167~175, 2009.3

3. wang xiao-yong, lee han-seung, Modeling the hydration of concrete incorporating fly ash or slag, Cement and Concrete Research, volume 40, pp.984~996, 2010