초고성능 콘크리트의 수화모델에 대한 연구

Analysis of hydration of ultra high performance concrete

왕하이롱* 왕 소 용**
Wang Hai-Long Wang Xiao-Yong

Abstract

Ultra high performance concrete (UHPC) consists of cement, silica fume (SF), sand, fibers, water and superplasticizer. Typical water/binder-ratios are 0.15-0.20 with 20-30% of silica fume. The development off properties of hardening UHPC relates with both hydration of cement and pozzolanic reaction of silicafume. In this paper, by considering the production of calcium hydroxide in cement hydration and its consumption in the pozzolanic reaction, a numerical model is proposed to simulate the hydration of UHPC. The degree of hydration of cement and degree of reaction of silica fume are obtained as accompanied results from the proposed hydration model. The properties of hardening UHPC, such as degree of hydration of cement, calcium hydroxide contents, and compressive strength, are predicted from the contribution of cement hydration and pozzolanic reaction. The proposed model is verified through experimental data on concrete with different water-to-binder ratios and silica fume substitution ratios.

키 워 드 : 초고성능 콘크리트, 수화모델, 수화열, 압축강도
Keywords : ultra high performance concrete, hydration model, heat of hydration, compressive strength

1. Introduction

Ultra high performance concrete (UHPC) is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. As shown in references [1-2], the development of properties of silica fume blended concrete or UHPC relates with degree of hydration. In this paper, a numerical model is proposed to simulate the hydration of UHPC. The degree of hydration of cement and degree of reaction of silica fume are obtained as accompanied results from the proposed hydration model.

2. Hydration model of Portland cement

The shrinking-core model, which was originally developed by Tomosawa [1], is used in this study to simulate the development of cement hydration. The modeled cement particles are assumed to be spheres surrounded by hydration product. Based on this theory, the rate of cement hydration is derived as follows:

$$\frac{d\alpha}{dt}=\frac{3\left(S_w/S_0\right)\rho_w C_{w-free}}{(v+w_g)r_0\,\rho_c}\frac{1}{\left(\frac{1}{k_d}-\frac{r_0}{D_e}\right)+\frac{r_0}{D_e}(1-\alpha)^{\frac{-1}{3}}+\frac{1}{k_r}(1-\alpha)^{\frac{-2}{3}}}$$

where α is the degree of cement hydration; v is the stoichiometric ratio by mass of water to cement (= 0.25); w_g is the physically bound water in C-S-H gel (= 0.15); ρ_w is the density of water; C_{w-free} is the amount of water at the exterior of the C-S-H gel; and r_0 is the radius of unhydrated cement particles.

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

3. The simulation of pozzolanic reaction in cement-silica fume blends

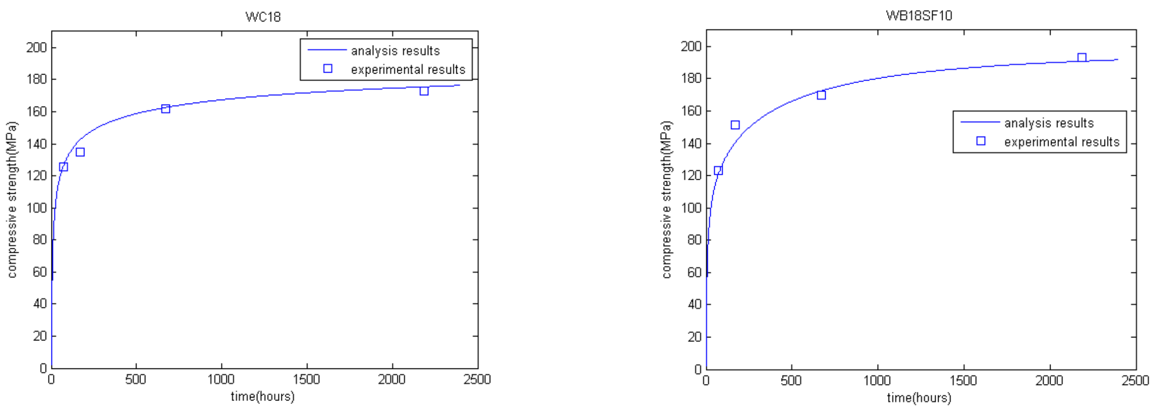
Because of the high specific surface of silica fume and great pozzolanic activity, in this paper it is assumed that the hydration of silica fume includes two processes: phase–boundary reaction process and diffusion process. Considering these points, based on the proposed method by Saeki and Monteiro [1], the hydration equation of silica fume can be written as Eq. (2–1) and (2–2):

$$\frac{d\alpha_{silica}}{dt}=\frac{m_{CH}(t)}{m_{silica0}}\frac{3\rho_w}{v_{si}r_{si0}\rho_{si}}\frac{1}{\frac{r_{sio}}{D_{esi}}(1-\alpha_{silica})^{\frac{-1}{3}}-\frac{r_{si0}}{D_{esi}}+\frac{1}{k_{rsi}}(1-\alpha_{silica})^{\frac{-2}{3}}}$$

Where $m_{CH}(t)$ is the calcium hydroxide mass in a unit volume in hydrating cement–silica fume blends. v_{si} is the stoi–chiometry ratio by mass of CH to silica fume. r_{si0} is the radius of silica fume particle. ρ_{si} is the density of silica fume. $Desi$ is the initial diffusion coefficient and k_{rsi} is the reaction rate coefficient.

The development of compressive strength of blended concrete f_c can be evaluated through Powers' gel space ratio x_{fc} strength theory, as

$$f_c = Ax_{fc}^{\ n}$$



(1–1) control concrete (1–2) water to binder ratio 0.18 with 10% silica fume

그림.1 Evaluation of compressive strength of UHPC

4. conclusions

This paper presents a general procedure to evaluate the development of properties of hardening UHPC. The degree of hydra–tion of cement and degree of reaction of SF are obtained as accompanied results from the proposed hydration model. The devel–opment of compressive strength of UHPC is evaluated through Powers' strength theory considering the contributions of cement hydration and SF reaction. Predicted compressive strength curves were compared with experimental data and a good correlation was found.

감사의 글

본 연구는 국토교통부/국토교통과학기술진흥원 건설기술연구사업의 연구비지원(13건설연구A02)에 의해 수행되었습니다.

참 고 문 헌

1. Wang XY, Lee HS. Evaluation of the mechanical properties of concrete considering the effects of temperature and aging. Constr Build Mater 2012; 29: 581~590
2. Xiao–Yong Wang, Han–Seung Lee. Modeling the hydration of concrete incorporating fly ash or slag.Cement and Concrete Research 40, pp.984~996, 2010