CHAPTER 2

LITERATURE REVIEWS

Autogenous shrinkage is caused by loss of water by hydration of cement. It is true that this type of shrinkage is very small in normal concrete and has been neglected. However, autogenous shrinkage should be considered for the concrete which has lower to binder ratio like high strength concrete or high binder content like self-compacting concrete. As the result of autogenous shrinkage, it should be taken into consideration as a cause of crack generation. With the development of the study of concrete, the results of investigations involve the cause of autogenous shrinkage and its mechanism, various influencing factors and different methods used for reducing autogenous shrinkage are now being accumulated.

2.1 Parameters Influencing Autogenous Shrinkage

Tazawa and Miyazawa (1993) studied autogenous shrinkage of concrete and its importance in concrete technology by considering the influence of each parmeters and proposed the model. Autogenous shrinkage of cement is influenced by mineral compositions of cement and their hydration ratio. The model is derived from a regression analysis for autogenous shrinkage as a function of the hydration ratio of each mineral and each mineral content for various types of cement at a constant water-cement ratio of 0.3. It is clear that the C_3A and C_4AF have a great influence on autogenous shrinkage.

Justnes, et al (1998) studied the influence of cement characteristics on chemical shrinkage. The total and external chemical shrinkage were determined for 10 different Portland cements with a wide range of mineral composition and fineness. For their different in mineralogy, increased fineness and increased content of C_3S and C_3A clearly contributes to increasing early shrinkage. It is important to note that the chemical shrinkage of the C_3A reaction to ettringite is much higher ($\approx$ 5 times) than the reaction of C_3S.

Mak, et al (1998) studied temperature effects on early age autogenous shrinkage in high performance concretes. The results obtained from unrestrained autogenous shrinkage measurements on a range of high strength concretes with and without silica fume. The dual effects of hydration-induced autogenous shrinkage and the counteracting thermally induced expansion significantly influence the early age unrestrained autogenous movements in a range of HPCs with low water/binder ratios. Even a moderate temperature rise of 15 °C has a significant impact in reducing the early age autogenous shrinkage in some concretes by between 25 and 50%.

Tazawa and Miyazawa (1998) investigated various factors influencing autogenous shrinkage of concrete, such as the type of cement, water-cement ratio, volume concentration of aggregate are experimentally investigated for prediction model. It has been proved that the influence of aggregate on autogenous shrinkage after the age of 24 hours can be estimated with Hobbs' model for mortar and concrete with different volume contraction of aggregate. Autogenous shrinkage of concrete is strongly dependent on water-cement ratio. It can be seen that the ultimate value of autogenous shrinkage increases with decrease in water-cement ratio.

For the influence of cement type, medium heat Portland cement and belite rich cement result in lower shrinkage than ordinary Portland cement. The intrinsic humidity in concrete with lower water-binder ratio is decreased by self-desiccation, and may become lower than ambient temperature. Then swelling may occur due to moisture absorption under higher ambient humidity.

2.2 Effect of Fly Ash on Autogenous Shrinkage

Sudsangium (1993) investigated the applicability of Mae-Moh fly ashes which contain different SO_3 contents as a solution to reduce autogenous shrinkage and comparing with fly ash from Hong Kong. The effect of autogenous shrinkage in terms of compressive strength, flexural strength and setting of cement pastes with and without Mae-Moh fly ashes and fly ash from Hong Kong are examined.

From the test results, it can be concluded that under sealed condition, fly ashes can be used for reducing autogenous shrinkage by their spherical particle which leads to larger free water content and SO_3 content of Mae-Moh fly ashes. The higher the SO_3 content, the larger the autogenous shrinkage reduction. Mae-Moh fly ashes are more effective in improving compressive strength and flexural strength.

Tangtermsirikul (1998) studied the effect of fly ashes with various chemical composition, particle sizes and replacement percentages on autogenous shrinkage of the pastes with fly ashes. It was found that for the effect of chemical composition, fly ash with higher SO_3 content resulted in lower autogenous shrinkage. For the effect of particle size, paste with fly ash having smaller average size than cement exhibited larger autogenous shrinkage whereas pastes with fly ash having bigger size than cement showed smaller autogenous shrinkage than that of cement paste.

For the effect of fly ash content, non-classified and classified fly ash which have larger average sized than cement showed the same tendency i.e. larger autogenous shrinkage in 20% fly ash paste than in 50% fly ash paste. On the other hand, smaller autogenous shrinkage in 20% fly ash paste than in 50% fly ash paste was found in case of pastes with classified fly ash having smaller average size than cement. It could be concluded that not only chemical composition which affect rate of hardening and volume change of pastes with fly ash but also particle size which affects the pore structure of the paste, has to be considered for modeling autogenous shrinkage of paste with fly ash.

Chan, et al (1998) researched on the effects of pozzolans and paste-to-aggregate ratio on autogenous shrinkage. The incorporation of fly ash in HPC leads to decrease in autogenous shrinkage, the higher the fly ash content, the lower the shrinkage. As part of OPC is replaced by fly ash, the amount of cementitious materials that undergoes hydration reaction was reduced and water migration in the pore structure is reduced substantially. It suggests that the concrete with higher p/a ratio may undergoes more autogenous shrinkage as the age increase, while concrete with lower P/A ratio does not exhibit as much shrinkage due to the restrain from the relatively higher amount of aggregates.

2.3 Pore Structure

Reinhardt (1994) studied the relation between microstructure and structural performance of concrete. Porosity, pore size and shape are important parameters to concrete behavior. After complete hydration, the some space is occupied by the hydrates and pores. Pores are divided into gel pores and capillary pores. It is assumed that the volume of physically bound water is equal to gel pores. The capillary pores are due to the volume contraction of chemically bound water (empty pores) and to evaporable surplus water not used during hydration. It is very obvious how a high w/c ratio and/or insufficient hydration increases the pore volume, especially of capillary pores.

Hanehara, et al (1998) investigated the relationships between the autogenous shrinkage, and the microstructure and humidity changes at inner part of hardened cement paste at early age. The autogenous shrinkage of hardened cement paste was closely related to its humidity reduction. Although there was a time lag between the autogenous shrinkage and the humidity change of hardened cement paste, no autogenous shrinkage took place in the cement paste prepared at w/c of 0.5 showing no humidity reduction. The autogenous shrinkage observed in the cement paste prepared at w/c of 0.25, therefore, is considered to be caused by the self drying at a relative humidity (RH) from 100 to 80%.

It is considered that the autogenous shrinkage takes place because the free water contained in pore particularly in fine gel pore formed by producing a large quantity of C-S-H is consumed by the hydration reaction and the humidity in the hardened cement paste is reduced. Production and phase conversion of aluminate hydrate products hardly related to the increase of autogenous shrinkage in this study.

Park, et al (1998) researched on relationship between autogenous shrinkage and hydration by investigating the effects of hydration reaction on the autogenous shrinkage phenomenon and the relationship between the autogenouis shrinkage and ratio of hydration. Autogenous shrinkage was found unexplainable solely by the hydration shrinkage of cement. In other words, there is a period during which autogenous shrinkage radically increases while hydration of cement scarcely proceeds. In this period, autogenous shrinkage is considered to occur because of capillary pressure produced by surface tension of water in the space of xerogel, and the decrease of distance between layers. From this standpoint, autogenous shrinkage can be considered by two mechanisms: hydration of cement and changes in the pore structure of hardened cement.

Maekawa, et al (1999) investigated the multicomponent heat of hydration model for the temperature analysis of massive concrete structures. A concrete performance model describes the hydration of cement in terms of the reactions of individual mineral components and expresses the differences between various types of Portland cement as difference in mineral composition.

2.4 Modeling of Autogenous Shrinkage

Chanmeka (1999) developed a model for predicting autogenous shrinkage in cement paste with various chemical composition of cement and fly ash. The model presented in this research is based on semi-microstructure consideration. It originated from some hypothesizes which concerned with the standing point that autogenous shrinkage is controlled by two mechanisms: first the progression of hydration in cement and secondly the changes in pore structure of the hardened cement paste. Water to binder ratio, temperature and chemical composition of cement and fly ash was though to affect both hydration and pore structure.

It is assumed that the shrinkage strains of cement-fly ash paste can be obtained from the summation of shrinkage strain which are contributed individually by cement and fly ash in the cement-fly ash paste deduction expansion caused by fly ash. The variation of water to binder ratio and temperature are considered to affect both hydration and pore structure development of hardened cement paste. The autogenous shrinkage contributed by fly ash is shown in Eq. (2.4), where the pozzolanic reaction P(t) was considered to depend on the ratio of the total SiO_2 to CaO in total binder. It was found that chemical expansion occurred in the paste with fly ash containing high SO_3. So, the expansion function was assumed to be expressed in term of SO_3 content in fly ash as shown in Eq. (2.5).

$$\varepsilon_{as}(t) = [\varepsilon_{as}'(t)\cdot\beta(\alpha_{av})] + \varepsilon_{FA}(t) - \varepsilon_{exp}(t) \tag{2.1}$$

$$\begin{aligned}\varepsilon_{as}'(t) = {} & 0.162\cdot m_{C_3S}\cdot\alpha_{C_3S}(t) + 0.131\cdot m_{C_2S}\cdot\alpha_{C_2S}(t) \\ & - 0.258\cdot m_{C_3A}\cdot\alpha_{C_3A}(t) - 0.803\cdot m_{C_4AF}\cdot\alpha_{C_4AF}(t)\end{aligned} \tag{2.2}$$

$$\beta(\alpha_{av}) = A\cdot\exp\left(B\cdot\frac{\alpha_{av}}{65}\right) \qquad A,B = f(w/b, T) \tag{2.3}$$

$$\varepsilon_{FA} = 0.025\cdot m_{FA}\cdot P(t) \tag{2.4}$$

$$\varepsilon_{exp}(t) = \frac{F}{G + \frac{1}{\exp(t)}} \qquad F,G = f(SO_3) \tag{2.5}$$

where $\varepsilon_{as}(t)$ = autogenous shrinkage strain of cement paste with fly ash (micron)

$\varepsilon_{as}'(t)$ = autogenous shrinkage strain contributed by hydration of cement in the cement-fly ash paste at water to cement ratio of 30% and temperature 20°C (micron)

$\varepsilon_{FA}(t)$ = autogenous shrinkage strain contributed by pozzolanic reaction of fly ash in the cement-fly ash paste (micron)

$\varepsilon_{exp}(t)$ = chemical expansion strain contributed by fly ash in the cement-fly ash paste (micron)

α_{av} = average degree of hydration (%)

$\beta(\alpha_{av})$ = parameter expressing the effect of pore structure on autogenous shrinkage

m_i = mass of each mineral compound (C_3S, C_2S, C_3A, C_4AF) per cubicmeter of cement paste at any water to binder ratio (kg/m^3)
m_{FA} = mass of fly ash in the mixture (kg/m^3)
α_i = degree of hydration of each compound in cement (%)
P(t) = pozzolanic reaction (%)
SO_3 = SO_3 content in fly ash (kg/m^3) of paste
w/b = water to binder ratio
T = temperature (°C)
t = age (days)

Hubert, et al (1999) proposed the model predicts the mean time-dependent shrinkage behavior of a plain structural concrete member which is exposed to a dry or to a moist environmental after curing. It should be point out that a major parameter to be taken into account when estimating concrete deformation properties is compressive strength. In reality, shrinkage and creep and strains do not depend on concrete compressive strength but rather on parameters related to the microstructure and concrete composition such as water/cement ratio, degree of hydration, properties of the aggregates etc.

The autogenous shrinkage may be calculated from

$$\varepsilon_{cas}(t) = \varepsilon_{caso}(f_{cm})\cdot\beta_{as}(t) \tag{2.6}$$

$$\varepsilon_{caso}(f_{cm}) = -\alpha_{as}\left(\frac{f_{cm}/f_{cmo}}{6+f_{cm}/f_{cmo}}\right)^{2.5}\cdot 10^{-6} \tag{2.7}$$

$$\beta_{as}(t) = 1-\exp\left(-0.2\cdot\left(\frac{t}{t_1}\right)^{0.5}\right) \tag{2.8}$$

where $\varepsilon_{cas}(t)$ = autogenous shrinkage at time t
$\varepsilon_{caso}(f_{cm})$ = notional autogenous shrinkage coeffcient from Eq. (2.7)
$\beta_{as}(t)$ = function to describe the time development of autogenous shrinkage, from Eq. (2.8)
f_{cm} = mean compressive strength (Mpa)
f_{cmo} = 10 Mpa
α_{as} = coefficient which depends on the type of cement
α_{as} = 800 for slowly hardening cements
α_{as} = 700 for normal or rapidly hardening cements
α_{as} = 600 for rapidly hardening high-strength cements
t = concrete age (days)
t_i = 1 day