CHAPTER 2

LITERATURE REVIEW

2.1 The Influence of Heat Reduction on Strength of Concrete

2.1.1 Hydration of cement

Strength development is much dependent on hydration of cement, and is closely connected with several structural formations of hardened cement paste with increase of hydration products. When Portland cement is mixed with water, its constituent compounds undergo a series of chemical reactions which are responsible for the eventual hardening of concrete. Reaction with water is designated as "hydration", and the new solids formed on the hydration are referred as "hydration product". The hydration reaction of main compound substance of cement could be considered as

1. Hydration reaction of calcium silicate (C_3S ,C_2S)

Calcium silicate will react with water and produce $Ca(OH)_2$ and calcium silicate hydrate (C-S-H) as shown below:

$$2(3\mathbf{CaO}.SiO_2)+6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O+3Ca(OH)_2$$

OR

$$2C_3S+6H_2O \longrightarrow C_3S_2H_3+3Ca(OH)_2$$

$$2(2\mathbf{CaO}.SiO_2)+4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O+Ca(OH)_2$$

OR

$$2C_2S+4H_2O \longrightarrow C_3S_2H_3+Ca(OH)_2$$

These reactions produce gel made up of two characteristics when it is hardening ; non-stable structure and porosity. C-S-H depends on ages, temperature and water to binder ratio.

$Ca(OH)_2$ causes cement paste to be base at pH 12.5. As a consequence, it can protect reinforcement from steel corrosion.

2. Hydration reaction of tricalcium aluminate (C_3A)

Hydration reaction of C_3A occurs suddenly and makes cement paste rapidly harden.

$$3\mathbf{CaO}.Al_2O_3+6H_2O \longrightarrow 3CaO.Al_2O_3.6H_2O$$

OR

$$C_3A+6H_2O \longrightarrow 3C_3AH_6$$

Gypsum is added to cement in producing process in order to retard the hydration of C_3A.

3. Hydration Reaction of tetracalcium aluminoferrite (C_4AF)

Firstly, hydration reaction of C_4AF reacts with gypsum and $Ca(OH)_2$ produces particles of sulphoaluminate and sulphoferrite as shown below:

$$4CaO.Al_2O_3.Fe_2O_3+CaSO_4.2H_2O+Ca(OH)_2 \longrightarrow 3CaO(Al_2O_3\ ,\ Fe_2O_3).CaSO_4$$

From Fig. 2.1, it can be seen that C_3A and C_3S are the most reactive compounds, whereas C_2S reacts much more slowly. Rate of reactions bears no relation to strength development as shown in Fig. 2.2. Calcium silicate provides most of strength developed by Portland cement; C_3S provides most of the earliest strength, more or less 3 to 4 weeks and both C_3S and C_2S contribute equally for ultimate strength. The results from the reaction of C_3A and C_4AF slightly effect the strength development of concrete.

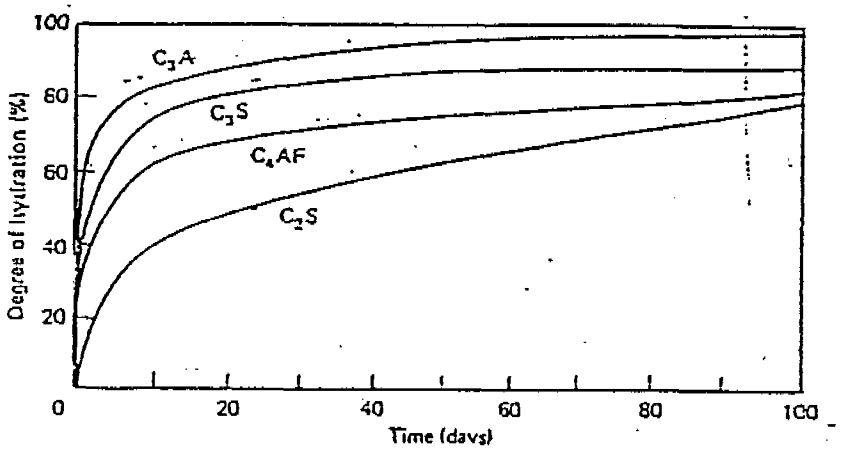

Fig. 2.1 The rate of hydration of the cement compound in a type I cement paste

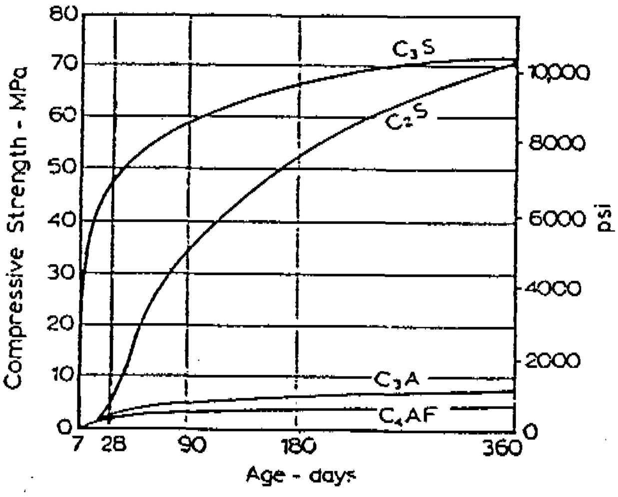

Fig. 2.2 Compressive strength development in pastes of pure cement compounds

2.1.2 Effect of fly ash on the hydration of cement and concrete

The interaction between fly ash and cement is a fairly complex phenomenon which involves several independent and interdependent processes. The effect of fly ash on the hydration of cement and clinker minerals depends on the chemical and physical nature of the fly ash and water to binder ratio of the mix proportion. The retarding of the hydration of both C_3A and C_3S, the main component of cement which greatly influences the early hydration process, is shown by heat evolution profiles over time (Ghose and Pratt 1981). The report referred to the attribution of the initial retarding of C_3S to aluminate ion in solution released from fly ash which could delay the nucleation and crystallization of C-S-H and $Ca(OH)_2$. The subsequent acceleration at the end of the induction period is attributed to increase the surface available for precipitation of hydration products provided by the fly ash particles. The C_3A retarding is attributed to Ca^{2+} and SO_4^{2-} in the solution produced by dissolution of fly ash. Furthermore, sulfate in fly ash is possible to retard the hydration more than the equivalent amount of the added gypsum (Plowman and Cabrera 1986). A physical effect in which the fine fly ash particles adhere to the surface of cement grain and hinder its interaction with water is another explanation of the retarding of fly ash.

2.2 Parameters Influencing Strength Development of Fly Ash Concrete

2.2.1 The properties of fly ash and its chemical composition on compressive strength

Yuan and Cook (1983) and Raba and Smith (1981) noted that concrete incorporating high-calcium fly ashes can be made on an equal-weight or equal-volume replacement basis without any significant effect on strength at early ages. Although, the rate of strength development in concrete tends to be only marginally affected by high-calcium fly ashes.

Gebler and Klieger (1986) indicated that the influence of class of fly ash on the long-term compressive strength of concrete was not significant.

Tikalsky et al. (1988) found that compressive and flexural strength of fly ash concrete was slightly lower at early ages than the conventional concrete but exceeds concrete without fly ash at later ages.

2.2.2 Fly ash reactivity

A pozzolan is defined as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

Pozzolanic activity is an indicative of the lime-pozzolan reaction but it is not very well understood. It is mostly related to the reaction between the reactive silica of the pozzolan and calcium hydroxide, producing calcium silicate hydrate.

The test result of the XRD technique, monitoring the progress of the lime update in pozzolan, indicated good correlation between the lime combined in the reaction and the compressive strength of mortars at 6 months and 1 year. In addition, ASTM C311 also describes the strength activity index with Portland cement and with lime at the ages of 7 days and 28 days.

The fineness of fly ash is one of the most important physical properties affecting pozzolanic reactivity.

2.2.2 Effect of temperature and curing regime on the strength development in fly ash concrete

Ravina's study (1981) concluded that a large amount of fly ash in concrete cured at elevated temperature significantly improves its compressive strength, but fly ash contributes less to the strength of concrete cured normally at ages of less than 28 days. Furthermore, curing coarse and fine fly ash concrete at elevated temperatures has a significant beneficial effect on the strength of the concrete at early and latter ages.

Gopalan and Haque (1987) reported the strength of normal and fly ash concrete cured in a fog room and in an uncontrolled environment. The strength of 91-day air-cured specimens was less than that of 7-day fog-cured specimens. On air curing, the percentage loss of strength increased with fly ash content and the curing period.

2.3 Modeling of Compressive Strength

Srichoo (1997) constructed a model for predicting temperature rise and compressive strength of Low Heat Concrete (LHC) with high volume fly ash. The model determined the effect of percentage of fly ash replacement and total cementitious material by the unit calcium oxide (C) content which is considered mainly to affect the temperature rise and compressive strength of LHC. The effect of water to binder ratio was considered as another parameter in the compressive strength model. The strength of LHC reduces as the fly ash replacement ratio increases at any age of concrete. The higher calcium oxide content results in higher compressive strength. The model can be obtained by adjusting the experimental data and expressed as:

$$f'_c = mC + k \tag{2.1}$$

where:

$m = -0.65 \times (w/b) + 0.54$

$k = 21.06 \times (w/b) - 12.78$

C = unit calcium oxide content obtained from total calcium oxide in both cement and fly ash per one cubic meter of concrete (kg/m^3)

Therefore , compressive strength at 28 days can be expressed as:

$$f'_c = [-0.65 \times (w/b) + 0.54]C + [21.06 \times (w/b) - 12.78 \tag{2.2}$$

Tangtermsirikul et al. (1999) constructed a model for predicting compressive strength of fly ash concrete. Initially, 28-day compressive strength is considered to vary with unit CaO content, ratio of water to binder (w/b) and ratio of paste volume to void volume of compacted aggregate phase (γ). The CaO is a dominant chemical composition in hydration reaction of both cement and fly ash. γ represents a relation of the availability of paste to fill void and to bond among aggregates. The 28-day compressive strength model can be expressed as:

$$f'_c = \{[(-84.7\ln(w/b)-0.0459)\times\log C]+[152.42\ln(w/b)+7.996]\}\times(1.12\times\gamma^{-1.1525}) \quad (2.3)$$

2.4 Special Concrete

Special concrete is defined as any concrete that is not conventional concrete.

2.4.1 Roller-compacted concrete

One of these special concretes is roller-compacted concrete. This is a no-slump concrete with an extremely low binder content, with a maximum aggregate of up to larger than 150 mm can be used. The concrete is placed by earthfill methods, that is transported by truck and compacted by a heavy vibratory roller in layers which become bonded. This method of construction is much faster than the conventional methods. Because of faster construction time, lower cost due to less labor and more enhanced durability, roller-compacted concrete is becoming an increasingly widely used material. Roller-compacted concrete has revitalized the construction of concrete gravity dams and associated works, and it can also be used in the construction of pavements. Greater use can be expected and thus a growth in the use of fly ash.

2.4.2 Self-compacting concrete

Self-compacting concrete which has excellent deformability and high resistance to segregation, and can be filled in heavily reinforced formworks without applying vibrators had been introduced. Therefore, many problems caused by vibrating, such as insufficient or excessive consolidation, vibration noise, and difficulties of vibration can be eliminated by using self-compacting concrete.