Chapter 11
Conclusions

Based on the experimental results and the proposed model, the following conclusions can be drawn.

1. Degree of hydration of each cement compound at a constant concrete temperature was formulated as the function of water to binder ratio and the concrete age. When fly ash is incorporated in concrete, a dispersion factor model was proposed to simulate the acceleration of reaction of cement at early age. The retardation factor of C_3S hydration was applied in the calculation of degree of hydration. The effect of temperature variation as well as the effect of relative water content were introduced into the degree of hydration and degree of pozzolanic reaction models. The proposed degrees of hydration and pozzolanic reaction were used to evaluate the behaviors of concrete such as heat evolution during hardening of concrete, free water content, specific heat, thermal conductivity and *CTE*.

2. Free water content of pastes and mortars decreased with respect to time due to water consumption in hydration and pozzolanic reaction and the formation of gel water. The replacement of cement by fly ash causes relatively higher free water content at early age but the free water tends to decrease in long term due to pozzolanic reaction. The time-dependent free water model was formulated and verified with the test results. The verification showed that the proposed model could be satisfactorily used to predict the free water content of the tested samples.

3. Specific heat depends largely on the amount of free water content since the specific heat of water is the highest among those of all ingredients of concrete. The replacement of cement by fly ash results in high specific heat at young age but the specific heat decreases in long term due to pozzolanic reaction. A series of equations were proposed to predict specific heat of fly ash concrete. The proposed equations can be used to simulate the trend and can be used to predict the specific heat of the authors' tested pastes and mortars and other researcher's tested paste, mortar, no-fine concrete and concrete with a certain degree of satisfactory.

4. Thermal conductivities of pastes and mortar increase just after mixing until about 3 days of age and are nearly constant after that. The use of fly ash reduces thermal conductivity of cement-fly ash paste. The addition of sand increases thermal conductivity of mortar. A series of equations were proposed to predict thermal conductivity of fly ash concrete. The proposed equations can be used to predict the thermal conductivity of the tested pastes, mortar and concrete. The comparison between the proposed model and the experimental results obtained from other researchers also shows satisfactory precision.

5. *CTE* of concrete is a time-dependent property which increases with age due to increased amounts of hydrated product and higher continuity of paste structure. The *CTE* of cement – fly ash paste increases from the first day and continues to increase in long term due to continuing pozzolanic reaction. Aggregate reduces the *CTE* of concrete. A higher *CTE* aggregate gives a higher *CTE* of concrete. Aggregate seems to be the main factor that affects

the *CTE* of concrete because it occupies most of the concrete volume. A *CTE* model of paste was proposed and was verified to be satisfactory for predicting the *CTE* of cement-fly ash paste. The model of concrete was also proposed and proved to be satisfactory to predict the authors' and other researcher's test results of the *CTE* of mortar and concrete.

6. Heat of hydration and pozzolanic reaction which were obtained from the modified adiabatic temperature rise model were used as the input for a commercial FEM program (MARC). The couple thermo-mechanical problem is used in the analysis. The temperature obtained from the thermal analysis is used as the input for the computation of the restrained strain. The temperature of concrete can be computed by relating the specific heat and thermal conductivity of concrete and the corresponding total heat generation during reaction process. The verifications showed that the proposed computerize model for predicting semi-adiabatic temperature is satisfactory for predicting temperature of the laboratory test samples and many real mass concrete footings.

7. The restrained strain is used to explain the restrained deformation in mass concrete. The restrained strain in tension ($\varepsilon_{res,\ ten}$) and tensile strain capacity (TSC) are used to described the cracking risk in mass concrete. If the $\varepsilon_{res,\ ten}$ is higher than TSC, the mass concrete structure is predicted crack. The model was verified with a real concrete footing of a construction project. The model is satisfactory to predict thermal cracking of the footing.

8. Based on the analysis of the sample mass concrete using the proposed model, it can be concluded that aggregate used in mass concrete should have low *CTE* to decrease the restrained strain. The use fly ash with higher CaO content increases temperature of mass concrete then the restrained strain is higher. The selection of mix proportion for mass concrete based on only compressive strength is not appropriate for mass concrete structure. The maximum temperature of mass concrete increases with the increase of the thickness of structure but the rate of increase becomes smaller when the structure becomes thicker. Mass concrete with larger s/v shows lower maximum temperature. The layer casting method is more effective for the control of thermal cracking than the block casting method. The insulation curing method is preferable for mass concrete and in order to prevent cracking, the center-ambient temperature difference and the surface-ambient temperature difference at the removal of insulation material should be controlled properly by providing long enough insulation curing period.