Chapter 8

Conclusions

8.1 Conclusion

Based on the experimental and the analytical results, the formulation and the verification of the carbonation simulation model, the following conclusions can be drawn.

1. Carbonation coefficient of concrete increased with the increase in fly ash content, water to binder ratio, and carbon dioxide concentration in environment. However, when compared to the cement-only concrete, carbonation coefficient did not change when a small amount of fly ash was used. When compared at the same fly ash replacement level, carbonation coefficients of the mixtures incorporating high-CaO fly ash were lower than those of the mixture with low-CaO fly ash. In addition, carbonation coefficients of concrete designed to have different paste content were about the same.

2. Carbonation coefficients were smaller for the specimens exposed with possibility of rain subjection (city-non-sheltered) than that without rain subjection (city-sheltered). For the cement-only mixtures and low volume fly ash mixtures (up to replacement of 30%), carbonation coefficients of mortars were approximately equal to those of the concrete that have the same mixture condition. However, for mixtures with 50% fly ash, carbonation coefficients of mortars were much higher than those of the concrete that had the same mixture condition.

3. From the relationship between carbonation coefficient and 28-day compressive strength, it was observed that when compared with the cement-only concrete, the carbonation coefficient increased with an increase in fly ash content, but was not influenced by type of fly ash. However, the carbonation coefficient was equivalent to the cement-only mixture when mixtures were incorporated with 10% of fly ash.

4. There were strong relations between the carbonation depth of concrete tested in the natural environments and that tested in the accelerated carbonation chamber. A linear equation was proposed to predict the carbonation depth in the natural environments based on the results obtained from the accelerated carbonation test and the square-root-t-law. The verifications showed satisfactory accuracies with the correlation coefficient higher than 0.9.

5. A model for predicting carbonation depth was also proposed in this study by taking into consideration of the migration of water in concrete, diffusion of carbon dioxide, and chemical reactions involving carbonation, hydration, and pozzolanic reactions within the concrete. Rate of gas diffusion was considered to depend on the pore characteristics of concrete, concentration gradient of the gas, and relative water content (also relative humidity for the diffusion of carbon dioxide) in concrete pores.

6. Based on the analysis using the formulated model and verification tests, the depth of carbonation increased with an increase in replacement ratio of fly ash, water to binder ratio, and carbon dioxide concentration in the environment, which is in consistent with the experimental results. The verification results were found to be satisfactory for the

prediction of relative water content, calcium hydroxide content, and carbonation depth of the tested concrete. This model can be used to estimate the carbonation depth of concrete with and without fly ash and subjected to different carbonation period. Therefore, this model is useful for the selection of materials, mix proportions and thickness of concrete cover for a specified depassivation period.

8.2 Recommendations and Further studies

1. The proposed equations in the carbonation depth prediction method that is based on the square-root-t law and the accelerated carbonation test are valid only for the environment within the tested range. It is necessary to extend study to obtain more test results in order to extend the applicability to a wider area of the country. In addition, the effect of curing duration and the applicability in high performance concrete should be studied and included in this simple method.

2. In the proposed carbonation simulation model, the effect that calcium carbonated precipitated from the carbonation reaction reduces the porosity of carbonated portion of concrete was not included. This effect reduces the coefficients of diffusion of water vapor and carbon dioxide and should be investigated.

3. In the presence of water, sodium and potassium contained in cement can dissolve into sodium hydroxide (NaOH) and potassium hydroxide (KOH). Although cement contains only a very small amount of sodium and potassium, these substances may affect the overall alkalinity in concrete. This effect is not considered in the proposed carbonation simulation model and should be investigated.

4. The verification of the proposed carbonation simulation model was proved to be satisfactory. However, verification tests in the long term period are recommended. This model is applicable to non-cracked concrete. The effect of crack needs to be considered in the future. The diffusion coefficients of carbon dioxide and water vapor in the crack concrete are normally larger than those in non-cracked concrete. The volume of carbon dioxide in cracked concrete was controlled by the crack width, crack depth, and the rate at which carbon dioxide penetrated the crack from atmosphere.

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