論　文　の　要　旨

題　目　A comprehensive study on the mechanical and durability properties of expansive concrete
（膨張コンクリートの力学特性と耐久性に関する包括的研究）

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Concrete shrinkage is a common phenomenon which can negatively affected the performance of the concrete. As shrinkage progressing, it may lead to formation of the cracks in the concrete which reduce the strength and service life of concrete. The application of expansive additives is considered as one of the most effective countermeasures for concrete shrinkage. Expansive additive can be classified into three categories based on their main constituents, but the type that mainly used in the concrete is calcium sulfoaluminate-based (CSA). This type of expansive additive induce expansion through the growth of ettringite produced by the hydration of CSA. When the concrete expansive energy is restrained with reinforcement bars, it may generate prestress in concrete and reinforcement. This mechanism is known as chemical prestressing. Chemical prestressing is associated with the improvement in concrete properties such as denser microstructure, better crack resistance, etc. Despite all the possible improvements, the usage of expansive additive for concrete is still quite low. The possible reason is due to the limited number of standards for designing expansive concrete. The lack of a standard for expansive concrete originated from the limited number of comprehensive studies related to the effects of different parameters on the properties of expansive concrete, especially the one that focused on durability performance.

In this dissertation, the new methods to predict mechanical and durability properties of expansive concrete are proposed. These methods were essential for the further development of expansive concrete design. The mechanical and durability prediction models were proposed from the results of three individual studies with various topics:

1) The strain prediction of cement products containing CSA-based expansive additives at ambient temperature
2) The comprehensive effects of expansive additive dosages, water-to-binder ratios (w/b), and curing conditions on compressive strength and air permeability of expansive concrete
3) The change in air permeability of expansive concrete considering the effects of specimen sizes, reinforcement ratios, and reinforcement arrangements.

To address the studies mentioned above, several experimental programs were conducted. First, the expansion prediction model was developed using thermogravimetric modeling with Gibbs-energy minimization software (GEMS) of expansive pastes with various w/b and expansive additive dosages. Thermodynamic modeling was used to estimate the hydration products including Portlandite, ettringite, etc. The accuracy of thermodynamic modeling was checked through the comparison with X-ray diffraction tests. The analysis was conducted to investigate the correlation between hydration products obtained from thermodynamic modeling and the strains of expansive mortars. The results indicated that it is possible to develop a simple model to predict the expansive strain of cement products containing CSA-based expansive additives based on the volume of ettringite produced by the hydration of CSA. The results were validated using mortars containing different types of cement and expansive concrete specimens.

Second, to understand the comprehensive effects of expansive additive dosages, w/b, and curing conditions on performance of expansive concrete, Cylindrical and prism specimens were cast with various expansive additives amounts and w/b. High dosages of the expansive agent and steam-curing treatment were applied to induce higher chemical prestresses in the concrete. Compressive strength and Torrent's air permeability measurements were performed to assess the mechanical and durability performances. The results indicate the effect of chemical prestresses on improving compressive strength; however, the air permeability performance generally suffers, which could be associated with microcracking. While steam-cured concrete experienced overall performance deterioration, supplying additional moisture could improve the air permeability but not the strength. Lowering the water-to-binder ratio was determined to be the most effective method for obtaining an improved performance for steam-cured CPC.

Third, the effects of specimen sizes, reinforcement ratios, and reinforcement arrangements the mechanism of air permeability changes of expansive concrete were studied by conducting Torrent's air permeability test to non-destructively evaluate the disparity in air permeability changes of expansive concrete during the drying processes from 28 to 182 days. Additionally, expansive strain changes were continuously monitored to investigate chemical prestress. The experimental test results suggest the immense effect of the change in expansive strain on the air permeability of concrete. This study proposes that the change in microstructure owing to the loss of expansive strain may cause an increase in air permeability. The loss of expansive strain is a distinguished feature that differentiates the mechanism of air permeability changes in expansive and normal concrete. These findings suggest the possible improvement in the durability performance of expansive concrete in cases where the loss of its expansive strain can be controlled.

The combinations of the information obtained from studies with different topics were used to propose the possible methods to predict the strengths and air permeability indices of expansive concrete. In the proposed models, compressive strength can be estimated based on the maximum chemical prestress data calculated from thermodynamic modeling. Meanwhile, the estimation of air permeability indices is conducted by inputting the shrinkage strain and the dosage of expansive concrete in the mixtures. Although the accuracies of the models are not proven yet, the prediction models can be a convenience starting point for the development of a standard for designing expansive concrete materials.