A FUNDAMENTAL STUDY ON SEAWATER-MIXED CONCRETE RELATED TO STRENGTH, CARBONATION AND ALKALI SILICA REACTION

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（強度・中性化・アルカリシリカ反応に着目した海水練りコンクリートの性状に関する基礎的研究）
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論 文 内 容 の 要 旨

In recent years, plenty of countries face a crisis of growing water scarcity. According to the report of the Organization for Economic Cooperation & the Development (OECD), nearly half of the worlds' population will inhabit in areas with severe water stress by 2030. Thus, a technology development is required for saving fresh water. From the viewpoint of saving fresh water, it is important to conduct research on utilization of seawater, which is approximately 96% of total global water on the earth. It implies that utilization of seawater has a very potential to improve technology of saving fresh water.

There are plenty of archipelagic countries such as Japan, Indonesia and others countries, where lots of peoples live in the distant and isolated islands. The transportation of fresh water and other materials for concrete production to distant and isolated islands will raise the cost of the concrete work. Hence, this research was carried out in order to evaluate utilization of seawater in concrete production and saving fresh water in the world.

This dissertation consists mainly of the seven chapters.

In **Chapter 1**, the background, problem statement, significance and contribution of this research are described. In this study, concrete mixed with seawater will be developed in durability aspects, such as carbonation and alkali-silica reaction (ASR). The strength development, carbonation characteristics and defect by ASR were investigated. The effects of seawater mixing, curing conditions, mineral admixtures and environmental exposure on strength development and these durability aspects were evaluated. Here, the durability of seawater mixed concrete against ASR was a newest contribution (novelty) of this research.

In **Chapter 2**, the results of previous researches on investigation of seawater in concrete mixture are reviewed. Some factors affecting the durability of sea water mixed concrete are reviewed. It was clarified that investigation on strength development of seawater mixed concrete is still contradictory amongst researchers, that is, seawater improves strength development of concrete. The positive opinion against concrete mixed with seawater is obtained for concrete incorporating mineral admixture, for example, GGBS. The largest percentage to the contribution affecting durability is carbonation. No investigation related to ASR of seawater mixed was viewed from 1974 up to now.

In **Chapter 3**, strength development and porosity of seawater mixed and tap water mixed OPC concrete, FA concrete and GGBS concrete with W/B of 40%, 50% and 60% in tap water curing (TC), seawater curing (SC) and air curing (AC) were evaluated up to 365 days. Besides, strength development of 25-year old concrete mixed with seawater was also investigated. The results showed that seawater mixing improves compressive strength up to 365 days of OPC concrete and FA concrete compared with tap water mixed concrete in TC, SC and AC.The effectiveness of seawater mixing on strength enhancement up to 365 days was larger for OPC concrete than FA concrete or GGBS concrete. Moreover, compressive strength up to 365 days of FA concrete and GGBS concrete in TC and SC is not influenced by mixing water. In addition, the compressive strength up to 365 days of seawater mixed concrete and tap water mixed concrete is not affected by type of curing water, tap water or seawater. It was also obtained that the porosity of seawater-mixed concrete was smaller compared to tap water-mixed in TC, SC and AC. Pore size distribution of seawater mixed concrete and tap water mixed concrete is not affected by type of curing water, tap water or seawater. Similarly, seawater mixing improves the compressive strength of concrete compared with tap water mixing, not only strength at short-term exposure (curing) but also strength at long-term, 25-year exposure. Also, strength development of tap water mixed concrete and seawater mixed concrete was not influenced by amount of chloride content in 25-year old concrete.

In **Chapter 4**, carbonation resistance of seawater mixed concrete and tap water mixed concrete using OPC and mineral admixtures (FA and GGBS) as binder were investigated. Also, carbonation of 25 years old concrete mixed with seawater and tap water were evaluated. The results exhibited that seawater mixing decreases carbonation depth of concrete with or without mineral admixtures in AC, and the carbonation rate of seawater mixed concrete in SC with and without mineral admixtures was smaller than that in TC. Mineral admixtures increased carbonation rate of seawater mixed concrete in all curing conditions, TC, SC and AC. The accelerated carbonation of tap water mixed and seawater mixed concrete with or without mineral admixtures was approximately seven times higher than that of natural exposure carbonation. In addition, seawater mixing improved carbonation resistance of concrete compared with tap water mixing, not only carbonation at short-term exposure, but also carbonation at long-term, 25-year exposure.

In **Chapter 5**, investigation on expansion behaviors of seawater mixed concrete and tap water mixed concrete with 50% W/B due to alkali-silica reaction (ASR) was conducted. The effect of mixing water, curing condition and mineral admixture on ASR-related expansion of concrete were evaluated. Results denoted that seawater mixed OPC concrete causes expansion due to ASR in all curing conditions, in TC, SC and MC. Besides, the effect of curing condition on ASR expansion of seawater mixed OPC concrete was larger in MC than that in water curing (SC, TC), and no significant distinction in the expansion level of seawater mixed OPC concrete was obtained in TC and SC. Mineral admixture such as FA and GGBS inhibited the expansion of seawater mixed concrete due to ASR in both SC and MC. In addition, influence of alkali on ASR-affected concrete was more deleterious for additional alkali (NaOH) than the alkali in seawater as mixing water, even with the same amount of alkali. In regard to pore solution, it was found that no relationship between alkali ions (Na^+ and K^+) concentration and hydroxyl ions (OH^-) in pore solution was obtained for all concrete mixtures. However, hydroxyl ions in pore solution were decreased by chloride ions (Cl^-) of seawater mix OPC concrete. Besides that, the expansion mechanism by ASR of seawater mixed OPC concrete was considerably influenced by alkali ions compared with a pH value in pore solution.

In **Chapter 6**, strength, carbonation and ASR of seawater mixed concrete were evaluated to provide recommendations related to applicability of seawater in concrete structures. Firstly, by considering strength, for seawater mixed OPC concrete, the maximum 50% W/C is recommended. Secondly, replacement of cement by FA 30% or GGBS 50% in seawater mixed concrete is recommended for inhibiting concrete damage due to ASR. Thirdly, the minimum of nominal cover depth related to carbonation-induced corrosion for service life of 50 years was 40 mm, 45 mm and 50 mm for S-OPC-AC, S-FA-AC and S-GGBS-AC, respectively. Fourthly, by considering the possibility of corrosion of reinforcing bars, it is recommended to use epoxy coated steel bar or stainless steel bar for corrosion resistance in concrete mixed with seawater in AC. Finally, seawater may be used as mixing water for plain concrete and reinforced concrete from the viewpoint of strength development, carbonation resistance and ASR damage.

In **Chapter 7**, conclusion and recommendation for research works in future are presented.