学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　Wang Ni

学 位 論 文 題 名

Experimental Investigation of Chloride Attack in Steam-cured Concrete with Supplementary Cementitious Materials under Salt-laden Environment in Cold Region
(混和材を用いて蒸気養生したコンクリートの寒冷地環境における塩害に関する実験的研究)

In the cold regions of Japan, the infrastructure element has to confront the problem of getting attacked by chloride ions from severe external resources such as seawater or deicing salt. Opting to prolong the lifespan by replacing the partially deteriorated members rather than demolishing them is a more sustainable, environmentally friendly, and cost-effective approach. Precast concrete as an alternative component can meet multiple requirements, and its versatility has attracted public attention. Steam curing is a widely adopted technique in precast concrete production, elevating curing temperatures while ensuring adequate humidity. However, research on the properties of steam cured concrete under different conditions remains limited. It is well-known that concrete incorporating fly ash and blast furnace slag can enhance durability and corrosion resistance. A calcium-aluminum additive, $CaO{\cdot}2Al_2O_3$, effectively binds chloride ions chemically to stable solids within the concrete, improving chloride resistance. Nevertheless, whether these benefits from Supplementary Cementitious Materials (SCM) still hold in steam-cured concrete has been the subject of limited study. This research aims to delve into this subject through two parts of research:
The first part of the research focuses on the chloride resistance of steam cured SCM concrete in cold marine environments. The concrete types are categorized into four groups, along with a reference specimen (N) that solely employs ordinary Portland cement, fly ash concrete (FA) with a cement replacement rate of 15%, blast furnace slag concrete (SG) with a replacement ratio of 50% and CA concrete (CA) with 7% substitute ratio of $CaO{\cdot}2Al_2O_3$ based additive. In normal-strength concrete with a binder-to-water ratio of 50% under three curing methods, the steam-air curing method involves one day of steam curing followed by 13 days of air curing (S); steam-water curing (SW) is 13 days of water curing after the steam curing in the first day, and the standard curing (W) is subjected to 27 days of water curing after demolding. Subsequently, all the specimens were relocated to the offshore area of Hakodate, Hokkaido, and subjected to one year of seawater exposure. The results indicated that pore size distribution was highly correlated with the types of binders and the curing methods. Furthermore, SG concrete exhibited low chloride ion diffusion coefficients (Dc) under three curing methods, while fly ash concrete tended to benefit from water curing. Notably, steam-cured normal-strength CA concrete had Dc of only 0.53 compared to the reference group after one year, despite the MIP showing an increase in the macroporosity In another set of high-strength concrete all adopted binders were the same but with a lower binder water ratio of 0.34 and no SW curing method. The conclusions of this part of the study include that the water binder ratio is the primary factor that affects chloride ion resistance based on a one-year exposure experiment. In sufficiently dense high-

strength concrete, the influence of binder types and curing methods on chloride resistance diminishes. Therefore, the chloride ion resistance of high-strength steam-cured CA concrete is not significantly affected by the additive.

The next part focuses on the use of high-early-strength steam-cured concrete for the double-layer reinforced concrete specimen to mimic a precast prestressed concrete bridge slab in a deicing environment, utilizing fly ash and blast furnace slag as SCM materials. The SCMs in this study is 20% replacement rate fly ash (FB) and 50% blast furnace slag (BB), and high early strength Portland cement is used as cement. The water-binder ratio of SCM concrete is 0.35, and the concrete without SCMs is 0.4. Additionally, specimens with the pessimism ratio of reactive andesite coarse aggregate were prepared to investigate the corrosion resistance of high-strength steam-cured fly ash concrete under the combined damage of ASR and chloride attack. Each concrete series was cast with five specimens to account for the uncertainty of steel corrosion in high-strength steam-cured concrete using a half-cell potential method. All specimens were exposed to 10% NaCl solution in a temperature-controlled room of 40 ° C. The experimental results proved that the steel bars in the SCM concretes did not corrode until the end of the three-year chloride exposure experiment and had an extremely low Dc of 0.32 cm^2/year for FB concrete and 0.29 cm^2/year for BB concrete. In contrast, the control specimens exhibited steel corrosion and abnormally high chloride ion diffusion coefficients due to wide longitudinal cracks caused by steel corrosion. The addition of fly ash plays a role in delaying the onset of ASR and inhibiting chloride penetration, thereby extending the onset of rebar corrosion in the concrete with ASR-risk.

In summary, this research clarified that the calcium-aluminum additive can effectively restrict chloride ion penetration in steam-cured concrete under cold marine exposure conditions although the pores of relatively larger size were increased. In addition, high-strength steam-cured concretes with fly ash demonstrated better resistance against the corrosion of steel bars even under combined chloride attack and ASR risk. Moreover, the half-cell potential method can effectively assess the corrosion condition of steel bars within the thick concrete cover of high-strength steam cured concrete, in which the disruption of daily traffic services will be avoided.