Seawater Resistance Evaluation of Existing NPP Concrete Structures Using High-sulfate Resistance Portland Cement

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1. Introduction

For nuclear power plant(NPP) structures exposed to marine environment, low-heat and high sulfate-resistance portland cement(Type V) with low content of C_3A has been widely used to restrain the occurrence of chemical erosion caused by seawater. Despite the superior sulfate resistance of Type V cement, however, questions have been raised on the efficiency of Type V cement for resisting the chloride ion, which is one of the major substances found in seawater. Accordingly, the ACI 357R revised in 1984[1] required that Type I or II cement containing 4~10% of C_3A be used. In addition, the standard specifications of Korea Concrete Institute (KCI) were revised in 1996 [2] in order to limit the use of Type V cement in the construction of marine concrete structures.

In this regard, the mechanical properties and seawater resistance of concrete using various kinds of cement have been studied to evaluate the durability of existing NPP structures using Type V cement as well as to manifest the regulatory position for the materials of concrete. This paper presents detail observations obtained through this study.

2. Experimental Investigation

In this study, an evaluation of the mechanical properties and seawater resistance has been performed for five kinds of concretes: .two concretes are made of two different kinds of Type V cement(C_3A contents of 1% and 4%, respectively), two concretes are made of two different kinds of fly ash cement(10% and 20% of the total weight of Type I cement are replaced with fly ash, respectively), and the other concrete is made of Type I cement. Table 1 shows the mix proportions of the aforementioned concretes.

Table 1. Mix proportions of concrete.

Cement Type	Specified Strength (MPa)	W/B (%)	s/a (%)	Unit Weight (kg/m^3)				
				W	B		S	G
					C	FA		
I	35	39.4	43.2	172	437	-	712	947
V				172	437	-	713	949
I+FA10%				172	393	44	705	937
I+FA20%				172	349	88	697	928

[Note] WRA = B × 0.38 wt.%., AEA = B × 0.002wt.%

The influences of cement types on the compressive strength, internal micro-structures, aggression characteristics of chloride ion, and sulfate ion of concrete have been investigated. The chloride-diffusion coefficient has been also calculated with equation (1) derived from Fick's Second Law and the soluble chloride amount measured at the depth of 2.25cm of the concrete test piece, which have been dipped in the chloride solution for 180 days.

$$C_{(x,t)} = C_0 \left[1 - \mathrm{erf}\left(\frac{x}{2\sqrt{D_e\, t}} \right) \right] \qquad (1)$$

where,

$$\mathrm{erf}(p) = 0.00194\, p^6 - 0.10522\, p^5 + 0.43814\, p^4 - 0.75950\, p^3 + 0.15175\, p^2 + 1.11076\, p \qquad (2)$$

in which C(x,t) is the chloride concentration (kg/m^3) at the material age of t and at the depth of x, C_0 is the chloride concentration(kg/m^3) at the surface, t is elapsed time(sec), x is depth(cm) from the concrete surface, D_e is the diffusion coefficient of chloride (cm^2/sec), and erf is the error function [3].

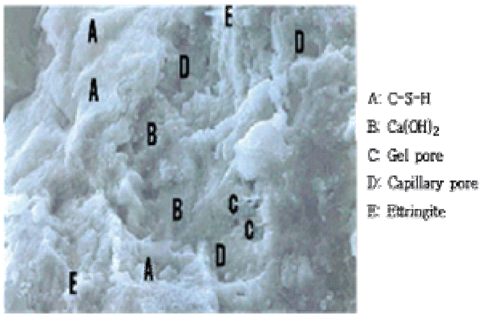
3. Results and Discussion

3.1 Compressive Strength

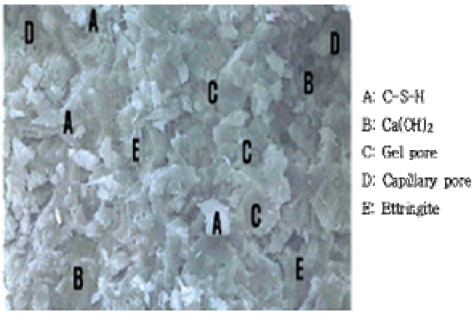
It has been observed that the compressive strength of the concretes using Type I and V cements is almost identical with increased age and the concrete mixed with fly ash has a higher compressive strength than the concrete made of Type I cement.

3.2 Internal Micro-structure

Through this study, it has been found that the concretes made of Type I and Type V cement have similar internal micro-structure. However, it is also found that the internal micro-structure of the concrete containing fly ash is denser than that of the concrete with Type I or Type V cement. This phenomenon could be caused by the pozzolanic reaction by which $Ca[(OH)_2]$ generated by the hydration of the cement reacts to the soluble SiO_2 and Al_2O_3 in fly ash to create insoluble C-S-H gel and C-A-H gel. the internal micro-structures of two concretes are shown in Figures 1(a) and (b).



(a) Type V Cement



(b) Type I Cement + Fly Ash 20%

Fig. 1. Internal micro-structures of concrete.

3.3 Aggression of Sulfate Ion

The concrete using Type V cement has greater resistance to sulfate than the concrete made of Type I cement because the Type V cement reacts with the sulfate ion and decreases the C_3A content, which generates the ettringite($C_3A \cdot 3CaSO_4 \cdot 32H_2O$).

On the other hand, it has been found that the pozzolanic reaction densify the internal micro-structure of the concrete using fly ash and the resistance to the damage caused by sulfate increases to almost the same degree as the case of the concrete made of Type V cement.

3.4 Characteristics of Aggression and Diffusion of Chloride Ion

The concrete using Type V cement has more severe chloride aggression than the concrete made of Type I cement or fly ash and the chloride aggression has a tendency to increase with time. In the case of Type V cement, the cement with C_3A content of 1% is weaker for the salt damage than the cement with C_3A content of 4%. This trend seems to be happen because the C_3A content related to the generation of Friedel's salt($C_3A \cdot CaCl_2 \cdot 10H_2O$) is small[4].

As the age of concrete increases, the pozzolanic reaction makes the micro-structure of the concrete using fly ash dense so that its resistance to salt damage is greater than that of the concrete using other cements.

In addition, the size of the diffusion coefficient of chloride ion can be arranged in the following order: Type V cement > Type I cement > Fly ash cement. Figure 2 plots the relationship between the compressive strength and the chloride diffusion coefficient of concrete for various cements. For concrete using Type V cement, it has been observed that the lower the content of C_3A, the lower the resistance to salt damage.

As the material age increase, the chloride-diffusion coefficient of the concrete containing fly ash decreases and eventually, it become smaller than that of the concrete made of Type I cement after dipping age of approximately 40 days. The internal micro-structure of the concrete becomes dense so that the infiltration and diffusion of the chloride ion are decreased by the pozzolanic reaction due to the fly ash with increase of the material age.

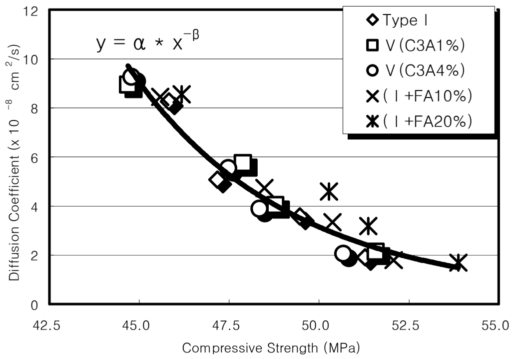


Fig. 2. Comparison of compressive strengths and chloride diffusion coefficients of concretes using various cements.

4. Conclusion

As a result of this study, it has been shown that the seawater resistance capacity of the concrete is ensured as long as Type V cement with C_3A content greater than 4% is used in the construction of marine structures. In order to improve the seawater resistance of marine structures to be built in the future, it is necessary to use an adequate amount (up to 20%) of good-quality fly ash mixed with cement.

References

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