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Deterioration Models of Concrete and Steel for a Long-term Performance Evaluation of Containment Buildings

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1. Introduction

Nuclear containment buildings are composed of several constituents that include concrete, reinforcement, pre-stressing tendon and liner plate. Long-term performance evaluations of these structures indicate that they can continue to meet their functional and performance requirements over a period significantly longer than their initial design life. However, there have been several instances that could challenge the capacity of the pre-stressed containment and other safety-related structures during the designed life time, if not remedied [1]. Therefore, it is indispensable to evaluate the performance of the composed concrete materials regarding the degradation characteristics.

From this point of view, the objective of this paper is to provide a summary of the results developed throughout the tests of structural materials and the development of deterioration models for nuclear containment structures over several years in KAERI [2]. These results provide background data and information that can be used to develop numerical models for the finite element analysis program NUCAS [3].

2. Degradation Tests

The mechanism of a typical aging degradation process of reinforced concrete (RC) structures is conceptually illustrated in Figure 1. The degradation process is divided into four stages such as the incubation period, the corrosion progress period, the crack propagation period and the structural deterioration period.

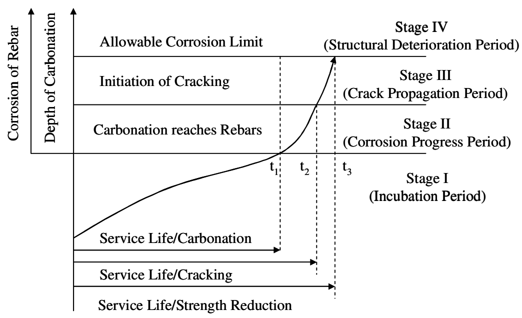

Figure 1. Mechanism of Typical Aging Degradation Process of RC Structures [4]

As mentioned, the reinforced concrete at nuclear power plants is composed concrete and steel such as a conventional reinforcement, pre-stressing steel and steel linear. Thus, as well as a degradation test for concrete, degradation tests for steels are carried out and the brief summaries follow.

2.1 Degradation tests for concrete

The durability of concrete materials can be limited as a result of as adverse performance of its cement-paste matrix or aggregate constituents under either a chemical or physical attack. In practice, these processes may occur concurrently to reinforce each other. In nearly, all chemical and physical processes influencing the durability of concrete structures, the dominant factors involved include transport mechanisms within the pores and cracks, and the presence of water.

Degradation tests for concrete mainly are conducted to find out the influence of combined deterioration conditions as well as single deterioration conditions such as chloride ion diffusivity, chloride attack, carbonation attack and sulfate attack.

Figure 1 shows one of the results of a strength change for concrete after being immersed in a sodium sulfate solution for different duration times as well as different cement contents. As shown Figure 1, the concrete strength is gradually decreased in accordance with the immersed time. Consequently, concrete strengths are significantly affected by the immersed time into the sodium sulfate solution than the cement contents.

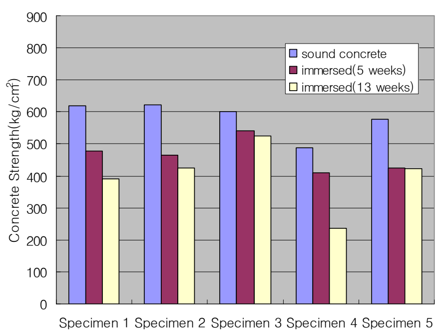

Figure 2. Graph for concrete strength verses specimen type for different immersing times

Table 1. Notation for the specimens in Figure 2

Specimen	Descriptions for specimens
Specimen 1	W/C;0.38, Portland cement, Fly ash 0%
Specimen 2	W/C;0.38, Sulfate-resisting cement, Fly ash 10%
Specimen 3	W/C;0.38, Sulfate-resisting cement, Fly ash 20%
Specimen 4	W/C;0.42, Sulfate-resisting cement, Fly ash 0%
Specimen 5	W/C;0.42, Sulfate-resisting cement, Fly ash 20%

2.2 Degradation tests for steel

In good-quality, well compacted concretes, reinforcing steel with a adequate cover should not be susceptible to corrosion because the highly alkaline conditions present within the concrete (pH>12) causes a passive iron oxide film to form on the iron surface.

The corrosion of the steel will result in a reduction in the effective steel cross-section and capacity. Thus, the accelerated corrosion tests for the steel material are conducted. Figure 3 shows a result of the corrosion tests for the cover thickness of the concrete. The thinner the concrete cover, the higher the concrete strain is at the same corrosion rates. That is, it indicated that a proper thickness of the RC structures is needed to prevent a steel corrosion from environmental deterioration facts.

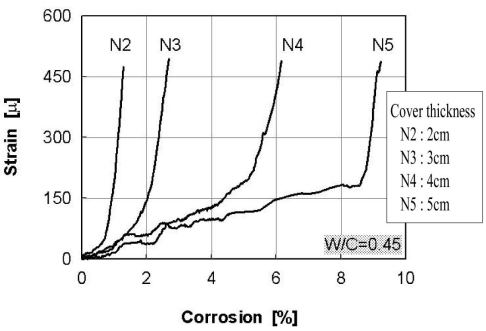

Figure 3. Surface strain-corrosion relationship for cover thickness [2]

3. Proposed Aging Models

From the laboratory tests, as mentioned above, several aging models are proposed. Table 2 shows the deterioration model of a concrete material regarding a chloride penetration, carbonation, freezing-thawing, alkali-aggregate reaction and sulfate attack from the deterioration tests.

The primary degradation factor for the structural steel and liner plate is corrosion. Corrosion and a loss of the pre-stressing force in the post-tensioning systems are most pertinent from a nuclear power plant aging management perspective. Consequently, the proposed aging models for the steel materials are summarized at Table 3. There are more details like notations and meanings of the parameters in reference 2.

Table 2. Proposed aging models for concrete [2]

	Proposed aging model
Chloride penetration	$C(x,t_n)=\sum_{k=1}^{n}C_k\left[x,(t_n-t_k-1)\right]-\sum_{k=1}^{n-1}C_k\left[x,(t_n-t_k)\right]$
Carbonation	$x_c=\sqrt{\frac{2D_{nom}\Delta c}{a}\cdot c\times\sqrt{k_1k_2k_3}\left(\frac{t_0}{t}\right)^n}$
Freezing and thawing	$DF=\upsilon_1\upsilon_2\upsilon_3\cdot\left(a_0+a_1W+a_2C+a_3Air+a_4Air^2\right)$
Alkali-aggregate reaction	$\varepsilon^{arr}=H^m\cdot\frac{\varepsilon_0}{A_0}\left(1-A_0-e^{-k_0\exp\left(-\frac{E_a}{RT}\cdot t\right)}\right)\cdot f(\sigma)\cdot e^{\alpha\cdot t}$
Sulfate attack	$X_{spall}=\frac{EB^2c_0C_ED_i}{\alpha\gamma(1-\nu)}\cdot t_{spall}\cdot f(t)$

Table 3. Proposed aging models for steels [2]

	Proposed aging model
Reinforcement	$\varepsilon_{rust}=u_r-\Delta r_b^*/x_p+\Delta r_b^*$
Tendon	$P=P_0e^{-0.1424x}$
Liner plate	$W_L=\beta n$

4. Conclusion

This study presents an overview and brief summary of the past experimental studies on the development of deterioration models and tests of structural materials for nuclear containment structures. From the results on the deterioration process, aging models for the RC materials are derived. These models can be directly used to develop a numerical analysis program based on a finite element such as NUCAS codes.

Acknowledgement

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