Chapter 1

Introduction

1.1 Background and Need of Research

1.1.1 Structural Standard Revision in Korea, 2012

Reinforced concrete is the most widely used structural material from the industrial era of increasing demand for housing so far.[1] Structural standard of these reinforced concrete(hereafter RC) structures has been developed according to the needs of rationality, ensuring affordability, resource-saving, environmental protection, as shown in Fig. 1.1. In particular, the recent concerns about the sustainability of the global environment highlight the need of CO_2 reduction and green building in building industry and the financial obligations of carbon dioxide emissions is applied in some countries and will be applied to another more countries. Accordingly, structural standard was amended on the direction of activating green growth and new technologies such as high-strength and eco-friendly materials in KOREA, 2012.[2), 3)]

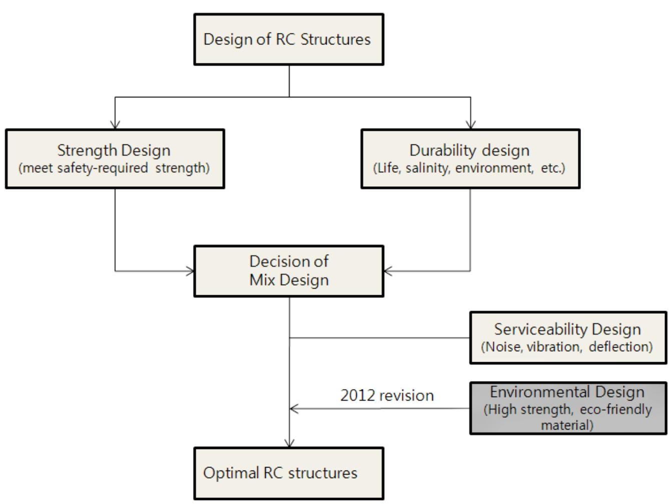


Fig. 1.1 *Design method of RC structure.*

1.1.2 A Qualitative Evaluation Limit of Concrete Carbonation Depth

Fig. 1.2 shows a process of durability deterioration by carbonation that is written in maintenance instructions of standard specification for concrete. This suggested that the life of RC structure is at the time of a rebar corrosion occurrence. Early degradation by this carbonation phenomenon such as acid rain, resulting from the rapid growth of the domestic industry since the 1970s and the increasing concentration of carbon dioxide in the atmosphere, have been reported recently.[5-8] Thus, in the case of urban corrosion initiation time by carbonation is important in terms of Durability.

In general, service life of RC structure by carbonation is evaluated at the time when the carbonation front (the color boundary between pink and colorless depth) reaches the depth of rebar in concrete using a phenolphthalein indicator considered the threshold of corrosion. Carbonation depth evaluation method using indicator could be clearly separated as shown in Fig. 1.3 (a) but in case of boundaries are ambiguous as shown in Fig. 1.3 (b) carbonation depth could be evaluated different by measurers. 10 mm carbonation depth measurement difference as shown in Fig. 1.4 causes a 25 years of service life prediction deviation.

Assessment methods between chloride attack and carbonation is compared in Fig. 1.5. In both cases, a qualitative evaluation method by using an indicator for measuring the depth of discoloration, progress of chloride attack and carbonation can be evaluated visually. In the case of salt damage quantitative evaluation can be possible by measuring chloride ion concentration at the depth of rebar location but in the case of carbonation there is still no quantitative evaluation method (evaluation materials, measurement position) and standard yet.

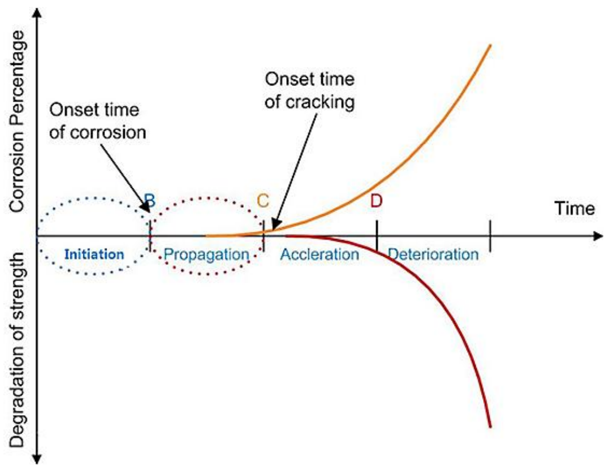
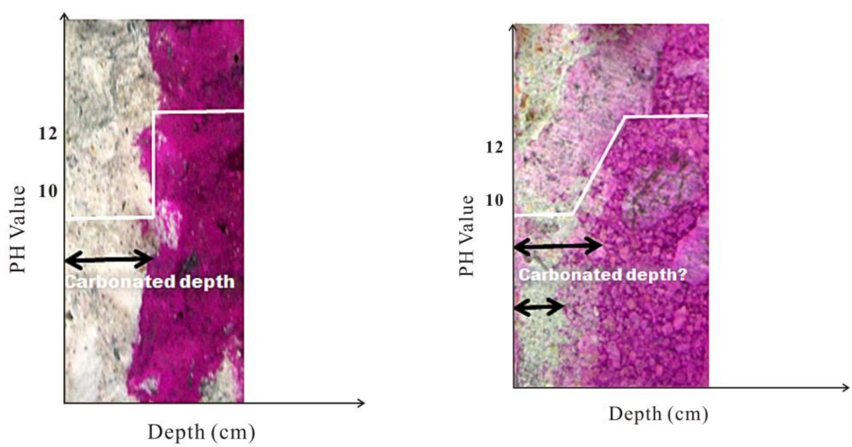


Fig. 1.2 *Deterioration by carbonation.*[4)]



a) If clarifies b) If the distinction is blurred

Fig. 1.3 *Carbonation depth evaluation by a phenolphthalein solution.*

Thus, evaluation method by indicator has a qualitative assessment limit that unstable color change may happen in the carbonation depth anytime. In addition, carbonation depth measurement method by the indicator has a problem that concrete color does not discolored in early progress of carbonation. Carbonation depth measurement method using an indicator may cause prediction error of service life of RC structure when measurement error by measurers has happened because of ambiguous boundary. Therefore, a quantitative evaluation methods and standards for carbonation are required to overcome this problem.

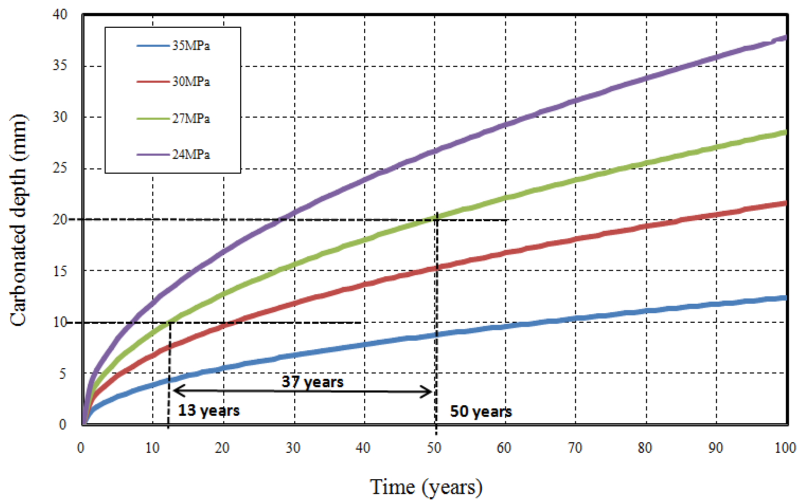


Fig. 1.4 *The service life prediction difference according to measurement error.*

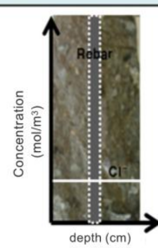
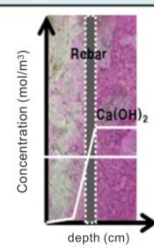
	Item	Chloride Attack	Carbonation
Quantitative assessment	Figure		
	Indicator	$AgNO_3$ solution	1% phenolphthalein solution
	Measure ment	Colored depth	Colored depth
Quantitative	Location	At the point of Rebar	?
	Material	Chloride ion	?
	Standard	1.2kg/m³	?

Fig. 1.5 *Comparison of evaluation methods for carbonation and salt attack.*

1.1.3 CO_2 Balance Evaluation of Concrete

Concrete carbonation is a phenomenon that indicating the strong alkali $Ca(OH)_2$ of cement hydration product in concrete reacts with CO_2 in the atmosphere to form a $CaCO_3$.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad \text{Eq. 1.1}$$

Fig. 1.6 shows the change in CO_2 concentration in the air in South Korea since 1999. The CO_2 concentration in the air has increased continuously by approximately 20 ppm from 1999 to 2007.[9)] The 4th United Nations Intergovernmental Panel on Climate Change (IPCC) report stated that global warming is clearly upon us and that increased greenhouse gases due to human activity may be the main reason[10)] and South Korea was the ninth largest producer of CO_2 gas emissions in 2004.[11)]

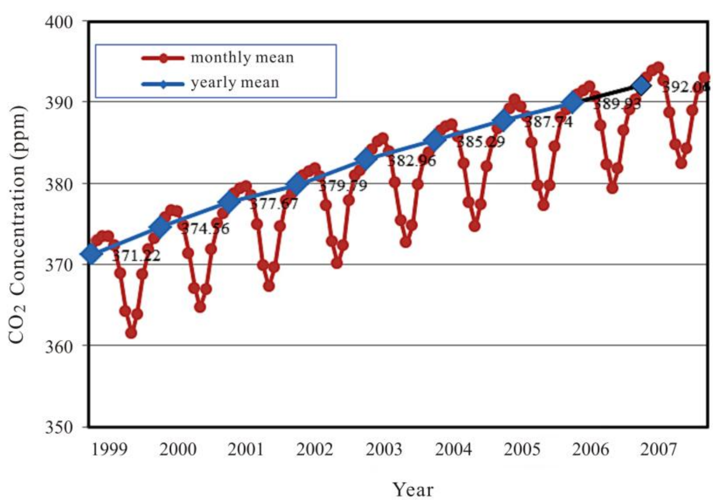


Fig. *1.6* *CO_2 concentration increase in South Korea.*

Especially, cement, which is a major constituent of concrete, emits a large quantity of CO_2 during the cement manufacturing process through decarboxylation of limestone and this makes people consider that cement is not an eco-friendly building material.

But concrete reabsorbs CO_2 gas in the air through carbonation during service life. Recently, some scientists have focused on concrete carbonation, such as carbon capture storage (CCS) and carbon capture reuse (CCR). Quantitative evaluations of CO_2 absorption through the carbonation of concrete have recently been reported in North America and northern Europe.[12, 13)]

However, there is no formula to calculate CO_2 absorption through carbonation yet. Even in case of equation 1.2, which is normally used, the ratio of CaO, which react with carbon dioxide is assumed different by researchers. (Claus Pade: 75%, Gajda: 32～37%) So, calculation result of CO_2 absorption is different by researchers.

$$CO_2 \text{ absorption(kg-}CO_2/m^3 \text{ concrete)} = 0.75 \times C \times CaO \times M_{CO2} / M_{CaO} \ (kg/m^3) \quad \text{Eq.1.2}$$

where,

M_i: the molecular weight of component M_i,

C: cement quantity of 1 m^3 concrete (kg/m^3),

CaO: CaO content of cement clinker (%).

In case of the above researchers, a maximum amount of carbon dioxide that concrete is capable of absorbing is calculated on the basis of concrete mix. But it is needed to know carbonation depth, degree considering service life of RC structure in order to calculate CO_2 absorption because CO_2 absorption is proportional to carbonation degree of concrete in a real condition.

1.2 Objectives of Research

The objective of this study is to establish a quantitative evaluating method that overcomes the limitation of qualitative evaluation, which is carried out using the naked eye with respect to the color change boundary by spraying indicator. Carbonation depth becomes the basic data for estimating the residual life and durability of RC structures. To achieve this objective, the quantitative change of $Ca(OH)_2$ and $CaCO_3$ for each depth in concrete according to the carbonation process is measured using TG/DTA in order to propose a quantitative method and an evaluation basis. Another one is to propose evaluating method of a CO_2 absorption quantity in the air through carbonation and how to evaluate $LCCO_2$ (emission-absorption of CO_2).

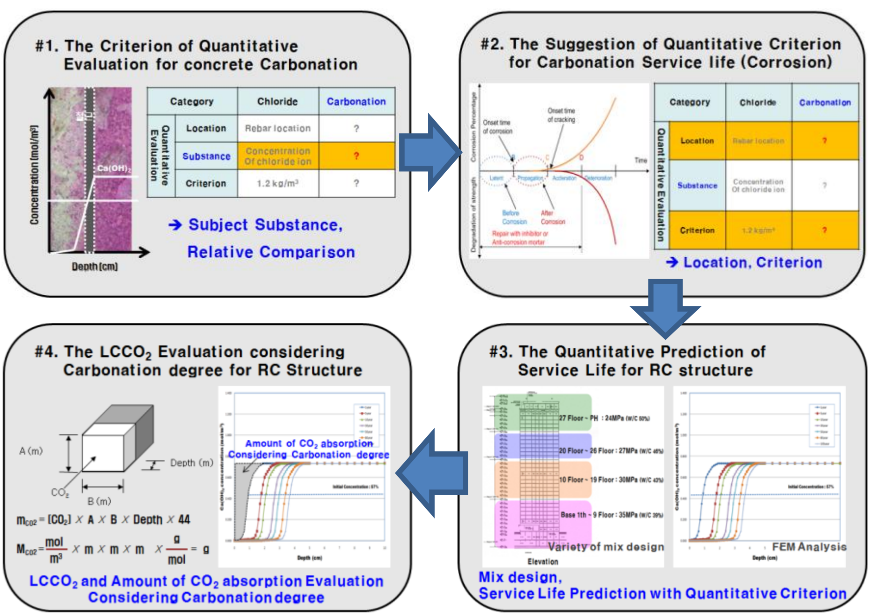


Fig. 1.7 Correlation of research objectives.

The specific goals of this study are the same as below, correlation between each objective is shown in Fig. 1.7.

a) Proposal of a quantitative evaluation basis for carbonation depth

b) Proposal of an evaluation basis for service life of concrete against carbonation

c) Prediction of service life for carbonation using proposed basis

d) Evaluation for a CO_2 absorption quantity in the air through carbonation and $LCCO_2$ (emission-absorption of CO_2) during service life

1.3 Configuration and Contents of Research

This study is composed of six chapters as below and progressed sequentially in order to accomplish objectives.

Chapter 1. Introduction.

Necessity and objectives of this study are explained.

Chapter 2. Literature review.

Review for carbonation and a quantitative evaluating method is conducted to support qualitative evaluating method by indicators.

- Definition of concrete carbonation and mechanism.
- A quantitative evaluating method and substances for concrete carbonation
- Relation between carbonation and rebar corrosion.
- Prediction model of concrete carbonation.
- Cement hydration model.

Chapter 3. Deduction of a quantitative evaluating basis for carbonation through a quantitative evaluation experiment.

Correlation between pH value and quantities of $Ca(OH)_2$, $CaCO_3$ is analyzed experimentally by carbonation weeks, concrete depths through accelerated carbonation experiment in order to propose a quantitative evaluating basis.

Quantity of $Ca(OH)_2$ is important to predict service life of concrete against carbonation and cement hydration model can predict it quantitatively to any concrete mix. Therefore, validation for cement hydration model is verified by comparing prediction valued using it and measured values of $Ca(OH)_2$.

Chapter 4. Prediction of service life using a quantitative evaluation basis.

Prediction model for carbonation based on FEM is used to predict the service life of RC structure. Required input data such as initial concentration of $Ca(OH)_2$, diffusion coefficient of CO_2, reaction velocity constant, CO_2 concentration in the air for FEMA are decided through literature review. The proposed quantitative evaluation basis in chapter 3 is used to evaluate and predict service life.

Chapter 5. $LCCO_2$ evaluation of RC structure during service life.

CO_2 emission of concrete considering concrete mix and CO_2 absorption through carbonation during service life for unit volume concrete is calculated quantitatively. And then, CO_2 balance (emission-absorption of CO_2) and $LCCO_2$ is evaluated quantitatively to a real building.

Chapter 6. Conclusion

Conclusions of this study are summarized and further study is proposed.