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A PROPOSAL ON PREDICTIVE METHODS OF LIFESPAN OF FULLY GROUTED REINFORCED CONCRETE MASONRY BUILDINGS ON CARBONATION RESISTANCE

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Abstract

This paper deals with a new method for predicting the life span of fully grouted reinforced concrete masonry buildings, which are positioned as a kind of casting permanent formworks as well as masonry. Life span is determined due to carbonation process in inner concrete through outer one on the basis of the total sum of carbonation resistance in every layer outside of reinforcement. The outer concrete of masonry units has generally an important role to control the life span in this type of grouted masonry constructions. It is induced that more than 30MPa in compressive strength can realize a life span more than 200 years, when a normal strength grout is used.

Key Words

Life span, Carbonation coefficient, Carbonation resistance

1 Introduction

Construction methods of Masonry buildings have evolved to meet the particular needs of climatic and sociological conditions. In Japan, strong earthquakes occur frequently, it is rainy throughout the year, cold in winter, and hot in summer; while there are many mega-cities having a lot of densely inhabited district, average age of population becomes drastically high, and a number of skilled craftsman on job sites has decreased year after year. Under such circumstance, new earthquake-resistant, fireproof, highly-durable, systematic (easy-to-construct) construction methods to create comfortable as well as safe and dwelling environment and to realize sustainable society have been required.

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Generally, masonry is characterized to be fireproof, to be highly durable if materials are used, to be earthquake-resistant if it's properly reinforced, and to appropriate have high design flexibilities. Masonry has been one of the most dominant alternative construction methods to be applicable for such Japanese climatic and sociological conditions. However, it has been applied only for low-rise as well as small-scale buildings in Japan, because of people as well as government agency's scepticism about masonry's earthquake resistant capacities.
From to 1984 to 1990, full scale seismic experiments for 5 stories-high (medium-rise) reinforced masonry structures were conducted in Building Research Institute, Tsukuba City, Japan, under Japan-US Cooperative Seismic Research Programs. Through such study, new design methods of fully grouted reinforced masonry structures and its construction systems were developed, and they have been authorized by Ministry of Construction and Transportation since April 2003, and given special amendments in seismic design of fully grouted reinforced masonry structures. According to such methods, fully grouted masonry is considered to be a hybrid structure consisting of masonry and reinforced concrete, and dealt to be a kind of reinforced concrete structures. From viewpoints of durability design of bearing walls, masonry units are considered to be a crucial component to cover reinforcement steels together with grout, just in the case of structural design.
This paper deals with effectiveness of masonry units in durability design of fully grouted masonry buildings; moreover, proposes prediction methods of their life spans by focusing on carbonation resistance of masonry units.

2 An Effectiveness of Masonry Units as Component to Cover Reinforcement against Deterioration Induced by Carbonation

2.1 Carbonation process and physical life span of reinforced concrete structures

It has been known well in the case of reinforced concrete buildings that there are various deterioration factors which can cause corrosion of rebars, such as concrete carbonation by carbon dioxide gas of the air, water and/or salt penetration through cracks of concrete, and so on; while those factors deteriorate bearing capacities of walls by mutually affecting each other in the following manner. At first, carbonation of concrete covering reinforcement proceeds to reach to the surface of reinforcement; secondly steel corrosion starts by water penetrating through concrete; thirdly, corrosion causes cracks on concrete, fourthly, more water penetrates into concrete through cracks; finally, walls lose load-bearing capacities. For the safety reason, conservatively, the physical life span of reinforced concrete structures is defined as the time, when carbonation depth of covering concrete become to be equal to its thickness; that is, when it is completely carbonated.

2.2 Carbonation Coefficient and Carbonation Resistance In Fully Grouted Concrete Masonry Bearing Walls

According to an established theory, in the case of monolithic concrete, carbonation depth is proportional to a square root of time, which is expressed in Equation 1;

$$D = A\sqrt{T} \text{ or } \sqrt{T} = D/A \text{ or } T = \left(D/A\right)^2 \quad (1)$$

where D represents carbonation depth (mm) ; A is called a carbonation coefficient which describes a velocity of carbonation (mm/day1/2 or mm/year1/2) which is

obtained through experiments (so-called accelerated carbonation tests); and T represents time (days or years).
On the other hand, in the case of fully grouted reinforced concrete masonry, materials to cover reinforcements are composed of masonry units (outer concrete) and grout (inner concrete), each component has different A and D expressed in Equation 2 and 3;

$$D_f = A_f \sqrt{T} \text{ or } \sqrt{T} = D_f / A_f \text{ or } T = \left(D_f / A_f\right)^2 \quad (2)$$

$$D_c = A_c \sqrt{T} \text{ or } \sqrt{T} = D_c / A_c \text{ or } T = \left(D_c / A_c\right)^2 \quad (3)$$

Where D_f is a carbonation depth of face shells, A_f is a carbonation coefficient of face shells, and D_c is a carbonation depth of grout, A_c is a carbonation coefficient of grout. Figure 1 describes such a comprehensive concept.

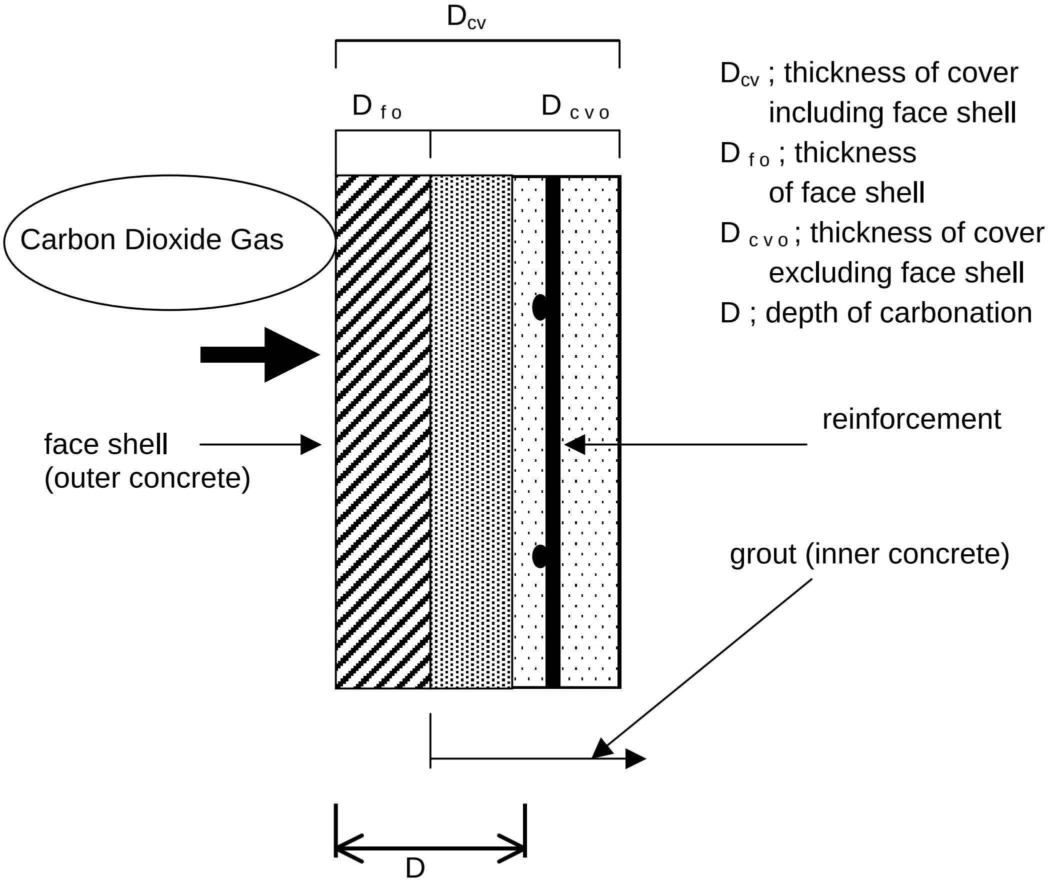

Figure1 Schematic Diagram of Components of Fully Grouted Reinforced Masonry Walls

Carbonation resistance describes a resistant capacity of concrete as a material against carbonation, and it is obtained by dividing its thickness (depth) by its carbonation coefficient; represented by R for monolithic concrete ($R = D/A$), R_f for face shells ($R_f = D_f / A_f$), and R_c for grout ($R_c = D_c / A_c$).
According to the study by Dr. Baba et al (1), carbonation coefficient of concrete is uniquely determined in relation to its compressive strength, no matter how it's made (e.g. wet-casting, dry-casting, vibro-pressing, or extruding) . Figure 2 and Equation 4

describes experimental relationship between carbonation coefficient and compressive strength;

$$A = B\left(1/\sqrt{F_c} - 1/\sqrt{61.3}\right) \qquad (4)$$

where A is carbonation coefficient, B is the experimental constant, and F_c is compressive strength of concrete.

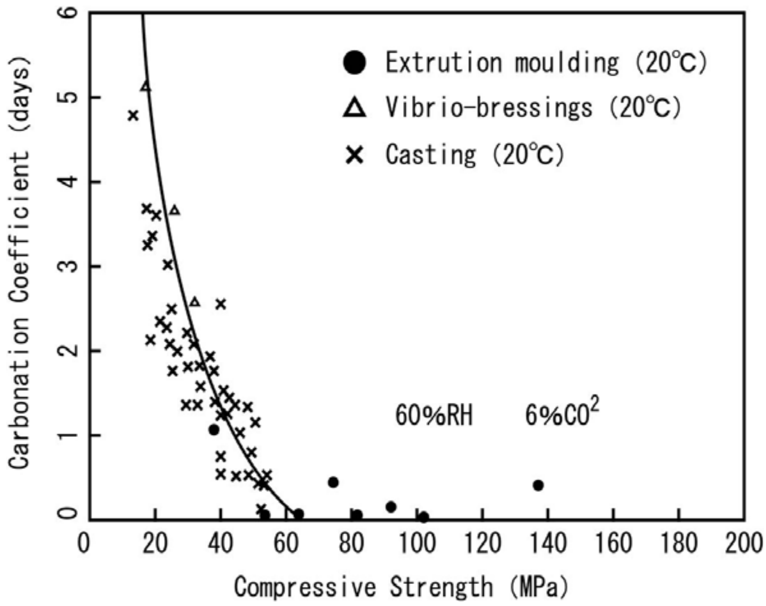

Figure 2 Experimental Results on Carbonation Coefficient of Face Material

2.3 Carbonation Process of Reinforced Concrete Masonry Bearing Walls

Load-bearing walls of fully grouted reinforced concrete masonry buildings are composed of concrete masonry units, grout, and steels for reinforcement. Their carbonation processes are different from the one in the case of monolithic concrete (2). In the case of fully grouted reinforced concrete masonry, carbonation begins with face shells of masonry units (outer concrete). After they are carbonated to their thickness, grout (inner concrete) starts to be carbonated. Figure 3 shows a schematic diagram of carbonation process in fully grouted reinforced concrete masonry walls.

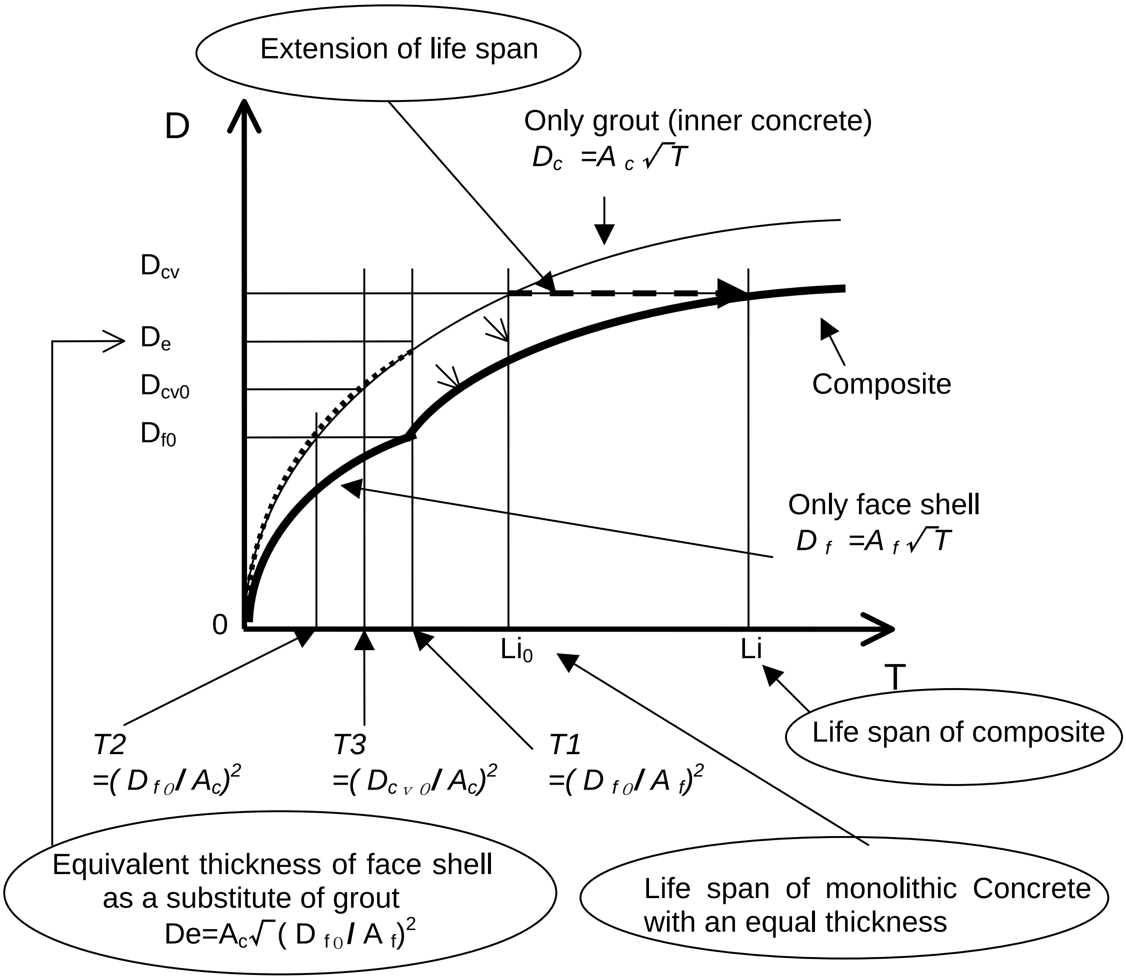

Figure3 A Schematic Diagram of Carbonation Process in Fully Grouted Reinforced Concrete Masonry Walls.

2.4 Actual Life Span of Fully Grouted Concrete Masonry

According to the time equivalent theory proposed by Dr. A. Baba et al (3), in fully grouted concrete masonry structures, the relationship between carbonation depth and time is expressed by Equation 5.

$$D = A_c\left(\sqrt{T} - R_f\right) + D_{f0} \qquad (5)$$

At the end of life, $D = D_{cv}$,and T=Li,

Then, Equation 5 is changed as follows,

$D_{cv} = A_c\left(\sqrt{T} - R_f\right) + D_{f0}$,

$\sqrt{T} = \left(D_{cv} - D_{f0}\right)/A_c + R_f$,

$\left(D_{cv} - D_{f0}\right)/A_c$ is expressed by R_c (carbonation resistance of grout)

$T = \left(R_c + R_f\right)^2$, Therefore, $L_i = \left(R_c + R_f\right)^2$,

,which means, life span of fully grouted masonry walls can be obtained by squaring the sum of carbonation resistance of face shell (outer concrete) and grout (inner concrete).

In other word, if the compressive strength of grout (inner concrete) is constant, life span of fully grouted reinforced concrete masonry walls is determined by the compressive strength of concrete masonry unit, that is, compressive strength of concrete masonry unit is very crucial as a determinant factor.

3 Experiments of the accelerated carbonation tests

The accelerated carbonation tests on various types of fully grouted masonry prism were conducted.

3.1 Properties of concrete masonry units and grout

The properties of concrete masonry units and grout are shown on Table 1.

Table1 Properties of concrete masonry units and grout

Notation of units	Size (mm)	Compressive strength (MPa)
1-A	390x190x150	9.5
1-B	390x190x150	13.1
1-C	390x190x150	17.1
1-D	390x190x150	18.2
1-E	440x190x150	18.9
1-F(grout)		26.5
G	390x190x190	31.4

3.2 Experimental Methods

For accelerated carbonation test, each grouted masonry prisms was cured for 28 days, and dried in the air for another 28 days. Then, those were saturated in gas (30 degree Centigrade, 60% RH, 5%CO^2). After 30 days, 60 days, 90 days, and 150 days exposure, and split at the centre. Then, the split surfaces were saturated in ethyl alcohol with phenolphthalein for 24 hours. Distance of white zone showing carbonated portion, were measured.

3.3 Experimental Results

The experimental results are presented by Figure 4 and 5, which shows that the higher the compressive strength is, the smaller the velocity of carbonation is, and the smaller the carbonation coefficient is. Moreover, the carbonation coefficient of the high-compressive concrete masonry unit is smaller than grout, which means face shells of concrete masonry units are highly effective against deterioration by carbonation, while low-compressive ones are carbonated very rapidly.

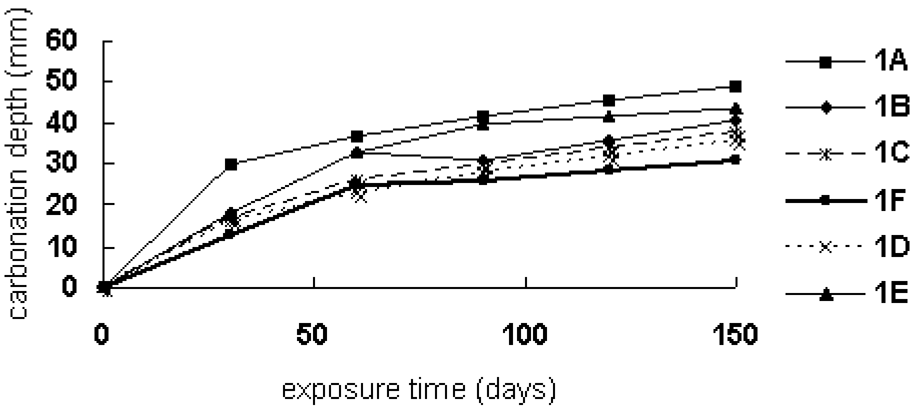

Figure 4 Carbonation Depth of Various Types of Concrete Masonry Prisms

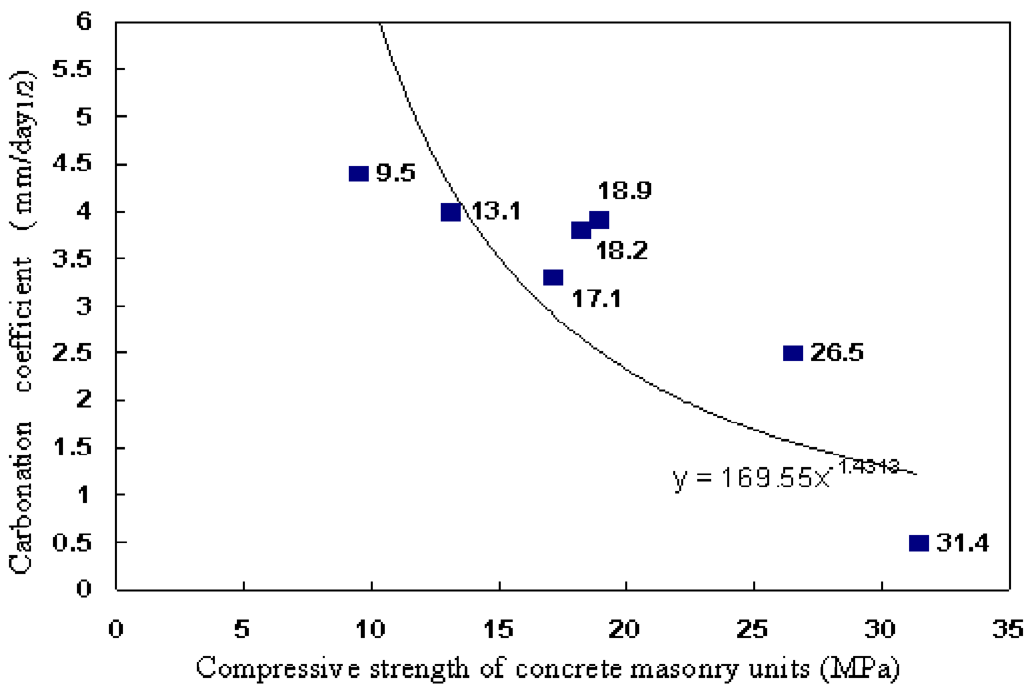

Figure 5 Relationship between Compressive Strength of Masonry Units and Carbonation Coefficient

4 Predictive method of life span of fully grouted reinforced concrete masonry buildings

Life span of fully grouted concrete masonry walls can be predicted in following manner:
Step1: Determine thickness of face shell of concrete masonry unit and grout covering reinforcement.
Step2: Determine compressive strength of concrete masonry unit and grout.
Step3: Determine carbonation coefficient of concrete masonry unit and grout by the experimental relationship between carbonation coefficient and compressive strength in concrete.
Step4: Determine carbonation resistance for concrete masonry unit and grout.

Step5: Predict life span of fully grouted reinforced masonry buildings by the Equation

$Li = (R_f + R_c)^2$

Usually, in architectural design, thickness of masonry unit and its face shell are determined by structural requirements. For seismic design, a volume of reinforcements is the most crucial together with compressive strength of masonry wall (prism) composed of masonry unit and grout. The volume of reinforcements affects sizes and shapes of hollow cores of concrete masonry unit. If a lot of reinforcements are required, a space for grout must be large enough. Normally, in structural design (seismic design) for fully grouted reinforced concrete masonry, an appropriate volume of grout is 50-70% of total volume of masonry wall. Assumed that the thickness of masonry wall is 200mm, the face shell's thickness is about 30-40 mm for each side. Once thickness of masonry unit and grout are determined in such a way, life span of fully grouted concrete masonry walls can easily be predicted.

5 Case study of prediction of life span of fully grouted reinforced concrete masonry walls by using the proposed predictive method

Assumed that there are two different types of grout (21MPa and 24MPa) are available in the market, while for structural design only 21MPa is required; from viewpoint of the expected life span, the compressive strength of masonry unit is determined as follows (shown on Figure 6).

When expected life span is 200 years, the compressive strength must be greater than 27.9MPa in the case that the strength of grout is 21MPa, while in the case that the strength of grout is 24MPa, only 25.5MPa is required for the strength of concrete masonry unit.

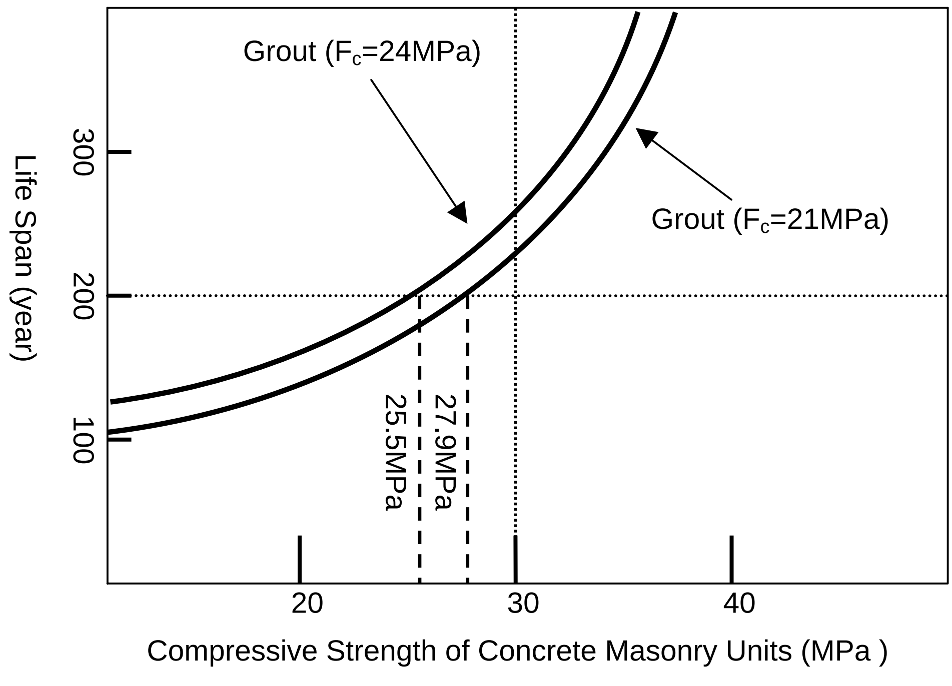

Figure 6 Relationship between Life Span and Compressive Strength of Concrete Masonry Units

6 Conclusion

1. In fully grouted reinforced concrete masonry buildings, concrete masonry units are very crucial to determine their physical life span.
2. The higher the compressive strength of concrete masonry unit is, the smaller the carbonation coefficient is.
3. The physical life span of fully grouted reinforced concrete can be predicted by carbonation coefficient (and/or carbonation resistance) of concrete masonry unit.

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