

Effect of Carbonation on High Strength Concrete (Carbonation Effect on Durability of Concrete)

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Abstract— Reinforcement corrosion is major cause of the deterioration of concrete structures. In the carbonation atmospheric carbon dioxide reacts with hydrated cement and destroys its alkalinity. This affected on concrete durability. The transport properties of concrete like permeability, capillary suction, diffusion and osmosis have been shown significant effect.

Keywords— Carbonation, Durability of HPC, Effect on compressive strength, Reinforcement corrosion

I. INTRODUCTION

Carbonation of concrete is traditionally defined as the chemical reaction between atmospheric carbon dioxide and the products of cement hydration particularly in accordance with the reaction. A major factor in concrete decay is carbonation caused by carbon dioxide in the atmosphere reducing the alkalinity of concrete. This is turn to attack by water and oxygen causing corrosion of the steel and spoiling of concrete sulphates from vehicles exhausts and chloride from de-icing salt also contribute to concrete degradation. Carbon dioxide in the atmosphere reduces the alkalinity of concrete. The alkalinity of concrete of concrete is between pH12 and pH13, the highly alkaline nature of the concrete results in the formation of a passivation layer on the reinforcing bars, preventing corrosion. A down level of alkalinity to pH 9.5 eliminates the passivation and protection, make concrete susceptible to attack by water and oxygen, leading to corrosion of reinforcing steel and eventually spoiling of concrete.

II. OBJECTIVES

- A. To find the compressive strength of M50 concrete exposed to carbonation.
- B. To find weight loss of M50 grade concrete due to carbonation
- C. To find out carbonation depth

Applying the new model to the accelerated test results gave a similar resistance against carbonation for the fine OPC as determined in the natural carbonation case where transport of CO₂ was the dominant step in the carbonation process. If the results would be interpreted the conventional model, a far too high resistance in carbonation would have been calculated, overestimating the service life of this fine OPC concrete in structural applications.

III. METHODOLOGY

Experimental methodology is adopted for dissertation work. The details of experimental work are as follows,

A. Casting of specimens

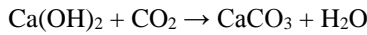
Casting of cube specimens of size (150 mm x 150 mm) and beam specimens of size (500 mm x 100 mm x 100 mm) M50 grade high strength plain concrete.

Specimens are kept in the carbonation chamber of size 6' x 6' x 6'. The concrete specimens are carbonated in the carbonation chamber and durations of carbonation 24, 48 and 72 hrs. are adopted for investigation. The carbonated surface becomes colorless after the application of phenolphthalein and uncarbonated surface is pink in colour. The temperature largely affects diffusion of gases and water, in the present investigation laboratory temperature of 27 degree Celsius is considered and kept constant. Specimens are tested for compression strength, flexural strength exposing to carbonation. The specimens are tested for their compression strength and flexural strength in compression testing machine and universal testing machine respectively. Comparison of result before and after temperature variations and carbonation.

B. Experimental Procedure

- Two type of specimens were prepared. Prisms measuring 50X50X300mm were cast for studying the degree of carbonation and 150 mm cubes were cast for measuring the impermeability index, pore volume and compressive strength of concrete. The specimens were kept in their moulds for 24 hrs. and then they were demoulded and cured for 28 days either in air or in the water.
- After curing, the prism specimens were transfer to the carbonation unit. Four sides, including the cast surface, of the cube specimens were coated with a carbonation resistance wax coating to allow CO₂ to enter only from two parallel opposite sides of the cubes. The first side was used for air permeability measurements, list other side supplied small sample to determine the pore volume. After the coating process the cube specimens were also placed in the carbonation unit.
- 28 days curing process, the concrete cubes taken out of tank of curing and tested under a compression testing machine of 2000 KN capacity. The average compressive strength of cubes are determined by testing.

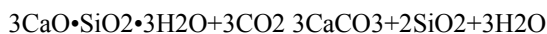
C. Chemical Reaction



The process of forming a carbonate is sometimes referred to as "carbonation", although this term usually refers to the process of dissolving carbon dioxide in water.

D. The water in the pores of Portland cement concrete is normally alkaline with a pH in the range of 12.5 to 13.5. This highly alkaline environment is one in which the steel rebar is passivated and is protected from corrosion. According to the Pourbaix-diagram for iron, the metal is passive when the pH is above 9.5.

- Several techniques have been proposed for analyzing the air permeability of concrete.
- The most well-known technique is the fig air permeability index.
- This technique is not suitable for the present investigation as it assesses the air permeability of concrete 20 to 50 mm below the surface of cubes.
- This depth is beyond the expected thickness of the carbonation layer and that's why the effect of carbonation can not be measured using this test. Other tests involve preconditioning techniques which pore structure, measure the permeability of concrete to specific gases.
- The vacuum test involves applying vacuum to the concrete surface using an air tight Perspex cap clamped to the test specimen. After the vacuum pressure inside the cap reaches 100 kPa below atmospheric, the vacuum is turned off and the time required regaining a pressure of 10 kPa below atmospheric within the cap is measured. This time is known as the impermeability index.
- Diffusion of CO₂ in the gaseous phase into the concrete pores,
- Its dissolution in the aqueous film of these pores,
- The dissolution of solid Ca(OH)₂ in the water of the o
- The diffusion of dissolved Ca(OH)₂ in pore water and its reaction with the dissolved CO₂,
- $\text{Ca}^{2+}(\text{aq}) + 2(\text{OH}^{-})(\text{aq}) + \text{CO}_2(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + \text{H}_2\text{O}$
- When Ca(OH)₂ is removed from the paste, hydrated CSH, C3S and C2S will also carbonate.



- The air-permeability of concrete cover and its relation with carbonation progress. In this study, two test cases were considered. One focused on the air permeability of new concrete and the other on that of existing concrete. In the test with new concrete, 20 concrete specimens with water-to-cement ratios ranging from 0.3 to 1.0 were prepared. The air permeability values of these specimens were measured at the age of 2 months; then, they were subjected to exposure tests. In the test with existing concrete buildings, the air permeability of concrete structures and carbonation

progress were measured for 4 buildings and 11 concrete specimens, the ages of which were 12–45 years.

IV. CARBONATION AND DURABILITY OF CONCRETE

A. Corrosion is an electrochemical process involving the flow of charges (electrons and ions). At active sites on the bar, called anodes, iron atoms lose electrons and move into the surrounding concrete as ferrous ions. This process is called a half-cell oxidation reaction, or the anodic reaction.

1) This initial precipitated hydroxide tends to react further with oxygen to form higher oxides. The increases in volume as the reaction products react further with dissolved oxygen leads to internal stress within the concrete that may be sufficient to cause cracking and swelling of the concrete cover.

2) Carbonation depth amount to only a few millimetres and cannot extend as far as the reinforcement.

3) Carbonation protection CO₂ – is not necessary. Where concrete quality is good and it is protected from the cause of concrete decay, carbonation is slight and eventually comes to a stop, with the depth reached being known as the maximum carbonation depth.

4) Carbonation has nearly reached the reinforcement layer. Carbonation protection is necessary in order to stop further progress. If carbonation penetrates deeper and reaches the reinforcement, the protection of the passivation layer around the rebar will be eliminated. If carbonation is stopped, the protection of the passivation layer will be retained and further decay of the concrete stopped.

5) The majority of the reinforcement is located in the already carbonated zone of the concrete. In this case, carbonation protection would be too late. The primary goal of surface protection is to protect the reinforcement from corrosion. If the concrete has already undergone carbonation, corrosion can only be prevented by waterproofing.

B. Carbonation Rate

After a 90 days of their preparation, the specimens 150 x 150 x 150 cm prismatic beam were placed in a chamber with constant parameters – temperature 28°C relative humidity 70 %, CO₂ concentration 6% and pressure 14 psi. Periodically during six months, the carbonation rate was measured in agreement with phenoftalein method on slides of 50 mm thickness.

C. Mix proportion for M50 grade concrete

TABLE I.

Cement	Water	Sand	Coarse Aggregate	SP
510 kg/m ³	148 kg/m ³	700 kg/m ³	1130 kg/m ³	7.65 kg/m ³

D. Factors affecting Concrete Carbonation

The rate of carbonation depends on porosity (for CO₂ to Diffuse) & moisture content of the concrete (for dissolution of solid Ca(OH)₂). The diffusivity of CO₂ depends upon the pore system of hardened concrete and the exposure condition. The pore system of concrete depends upon the type and the content of binder, water/binder ratio, and the degree of hydration. Thus, the main factors affecting concrete carbonation are:

- Pore system of Hardened Concrete which in turn depends upon w/c ratio, type of binder, and degree of hydration,
- Relative humidity (for dissolution of Ca(OH)₂),
- The concentration of CO₂ Optimal conditions for carbonation occurs at a RH of 50% (range 40–90%).
- If RH <40%, CO₂ cannot dissolve,
- If RH >90%, diffusion of carbon dioxide will be inhibited by the water that has filled the pores and hence CO₂ cannot enter the concrete.

The most dangerous range of relative humidity for carbonation is 40% to 80%, since the carbonation reaction calls for the presence of water, while under higher atmospheric humidity the diffusion of carbon dioxide will be inhibited by the water that has filled the pores.

E. Results

Weight Loss Effect : -

Concrete Grade	Specimen Size	Weight of Specimen (kg)	Weight after Carbonation (kg)	Weight loss
M 50	150x150x150	8.51	8.46	0.05

Compressive Strength After Carbonation : -

Period (Days)	Compressive Strength After Carbonation (N/mm ²)
7	33.65
28	51.21
56	45.15

CONCLUSIONS

- 1) Carbonation leads to a significant reduction in permeability of concrete.
- 2) The reduction is greatest in poor quality concrete
- 3) The carbonation depth increases with an increasing exposure time and higher CO₂ concentration results in higher carbonation depth for all mixtures.

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