An Experimental Investigation of the Effect of Carbonation on Properties of Plain Concrete

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Abstract
This study deals with the effect of carbonation on the mechanical properties such as compressive strength, modulus of elasticity and durability like depth of carbonation and porosity of the concrete using ordinary Portland cement over a time period of up to 120 days. To study the behavior of carbonation front of concrete in presence of varying water content, water binder ratios of 0.35, 0.50 and 0.65 are chosen. It is observed that compressive strength, modulus of elasticity and depth of carbonation are increased with time duration.

Keywords
compressive strength, modulus of elasticity, durability, and depth of carbonation

1. Introduction

One of the most prominent causes of deterioration of steel reinforcement in concrete is the carbonation, a process that involves the relapse of passive layer on the rebar due to the fall in the value of pH of concrete. It is the process of diffusion of carbon dioxide through the pores of concrete and its reaction with the hydration products such as calcium hydroxide and calcium silicate hydrates [1].

$$Ca(OH)_2\ (s) + CO_2\ (g) = CaCO_3\ (s) + H_2O$$

Among all phase changes, the one that involves the reaction with $Ca(OH)_2$ is most responsible for the de-passivation phenomena. The corrosion induced by carbonation can increase the possibility of crack development and decrease the durability of concrete [2]. The pore solution of concrete has a pH of about 12 to 13 [3]. The value of pH is said to have reached at a value of 8.3 once full carbonation of concrete was observed i.e., complete consumption of calcium hydroxide [4]. Though the value of pH of concrete remains in basic medium, it is the decrease in the value of pH that calls for an acidic environment. It is after the pH value reached lower than 11.5 [5], the destruction of passive film begins. The basic factors governing the process of carbonation are the quantity of pozzolanic material, the humidity conditions, and the duration of exposure [6, 7]. It is observed that the process of carbonation reduces the surface porosity of the concrete because the resultant of carbonation CaCO3 occupies a greater volume than $Ca(OH)_2$ [8]. The process of carbonation under natural conditions is usually slow due to the low concentration of carbon dioxide present in the surrounding environment, which is only about 0.04%. It is to overcome this tribulation; the process is accelerated using an environment of a higher concentration of carbon dioxide. Though it is still a speculation that the accelerated environment can stimulate the results of prolonged natural exposure, the results of accelerated carbonation conditions are still valuable to study the kinetic of carbon dioxide ingress into the concrete.

This paper deals with the study on the influence of water binder ratios on mechanical properties of concrete cured with accelerated carbonation for up to 120 days. The details of compressive strength, modulus of elasticity and depth of carbonation for all water cement ratios that are adopted are discussed.

2. Materials and Methodology

To measure the depth of carbonation and the mechanical properties of concrete at various stages of carbon dioxide intake, the exposure duration of concrete specimens is fixed to 7, 28 60 and 120 days of accelerated carbonation curing. The water binder ratios of 0.35, 0.50 and 0.65 are adopted.

Ordinary Portland cement of 43 grade was adopted for all mixes and its specific gravity was found as 3.15. Crushed basalt with a specific gravity of 2.77 was used as a coarse aggregate and fine aggregate has a specific gravity of 2.42. The coarse aggregates were in a size range of 12.5 to 20 mm while fine aggregates were in a range of 0.075 to 4.75 mm. This was in agreement to the specifications given in IS 2386 [9]. Water reducing admixture has been used to attain a slump of 100±20 mm. Its specific gravity was found to be 1.08. **Table 1** shows the physical characteristics of the cement used in the design mixture of the concretes.

Table1. Physical Characteristics of Cement

Physical Characteristics	OPC 43 grade
Density (kg/m^3)	3090.15
Specific gravity	3.15
Fineness (%)	8
Water demand (%)	33

The atmospheric concentrations of carbon dioxide are 0.04% by volume, but the samples in the accelerated carbonation chamber (ACC) are exposed to a carbon dioxide concentration of 5% to accelerate the process of carbonation. The relative humidity is kept at 60-70% and the temperature of the carbonation chamber is maintained between 25^{0}C to 35^{0}C. The design mix proportions for the various water binder ratios that were used are tabulated in Table 2. For the water binder ratio of 0.35, to maintain the desired workability, a super plasticizer is used by 0.9% the weight of cement.

Table 2. Design mix proportions of concrete.

Mix proportions for 28 day strength of 30-35 MPa in kg/m^3				
Water binder ratio	Cement	Water	Fine Aggregate	Coarse Aggregate
0.35	563	197	557	1088
0.50	394	197	655	1125
0.65	304	197	734	1114

Tests are conducted on the concrete specimens to determine its compressive strength, modulus of elasticity and depth of carbonation under accelerated carbonation conditions.

Compressive strength of a concrete is its capacity to withstand loads in axial direction. The cubes of dimension 150 × 150 × 150 mm^3 are cast with the nominal aggregate size not exceeding 20 mm and exposed to higher amounts of carbon dioxide in accelerated carbonation chamber. Compressive strength is measured by placing the cubes in the machine in such a way that the load is applied to opposite sides of the cubes as cast and by dividing the maximum load applied to the specimen during the test by cross sectional area.

Modulus of elasticity of concrete is measured by a cylindrical specimen of diameter 150 mm and height 300 mm. The axial load is applied and its compression is measured to find the modulus of elasticity. **Figure 1** shows the measure of modulus of elasticity of concrete.

The depth of carbonation is measured by spraying the phenolphthalein indicator on the specimen of concrete and the average of the values may be taken as shown in **Figure 2**.

Figure 1. Meaure of Modulus of Elasticity

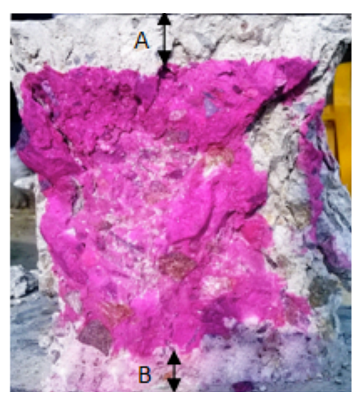

Figure 2. Meaure of depth of carbonation

3. Results and Discussions

The experimental results of the compressive strength, modulus of elasticity and depth of carbonation tests that have been carried out are produced below.

3.1 Compressive Strength

The results of compressive strength test for the water binder ratios of 0.35, 0.50 and 0.65 at the age of 7, 28 days of natural curing and 7, 28, 60 and 120 days of accelerated carbonation curing are presented in **Figure 3**. The compressive strength is seen to increase with the increase in duration of exposure to accelerated carbonation curing and decreased with the increase in the water binder ratios. This might be held responsible to the decrease in the porosity for the increase in duration of carbonation.

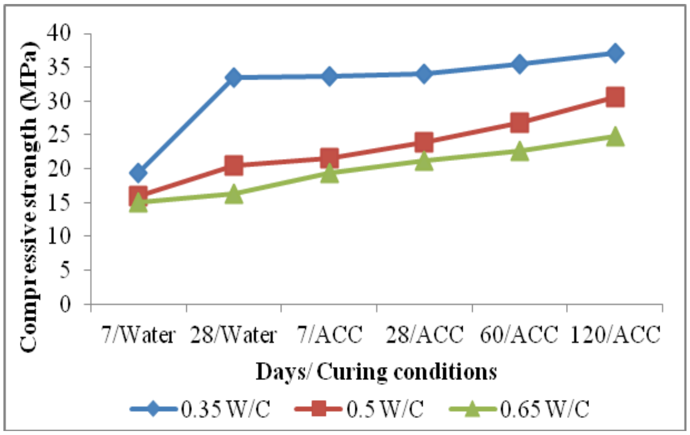

Figure 3. Variation of compressive strength of accelerated carbonated concrete with time

3.2 Modulus of Elasticity

Modulus of elasticity for the water binder ratios of 0.35, 0.50 and 0.65 at the age of 7, 28 days of natural curing and 7, 28, 60 and 120 days of accelerated carbonation curing are presented in **Figure 4**. The values of modulus of elasticity of cylindrical concrete specimen have increased with the increase in the age of curing in accelerated carbonation chamber. The values have decreased as the water binder ratio increased. This is accountable to the similar fact that increased the compressive strength. It is the decrease in the surface porosity that enabled the increase in mechanical properties.

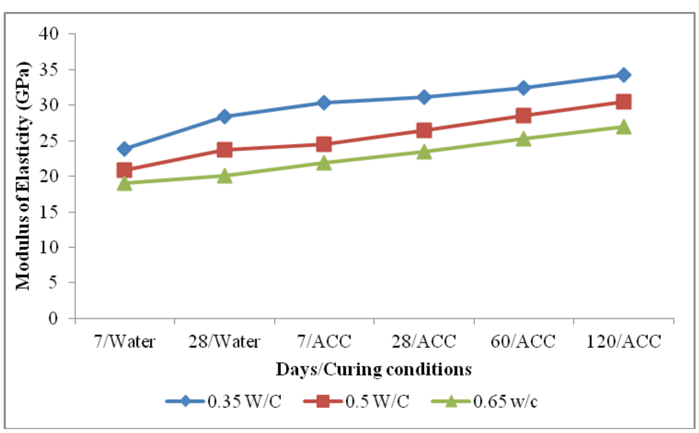

Figure 4. Variation of modulus of elasticity of accelerated carbonated concrete with time

3.3 Depth of Carbonation

Depth of carbonation for the water binder ratios of 0.35, 0.50 and 0.65 at the age of 7, 28 days of natural curing and 7, 28, 60 and 120 days of accelerated carbonation curing are presented in **Figure 5**. Results dictate that the depth of carbonation has increased with an increase in water binder ratio and age of curing in the accelerated carbonation chamber. This may be attributed to the high amounts of pore water present in the concrete with higher water binder ratios. The moisture content in the concrete plays a significant role in the amount of the carbon dioxide ingress.

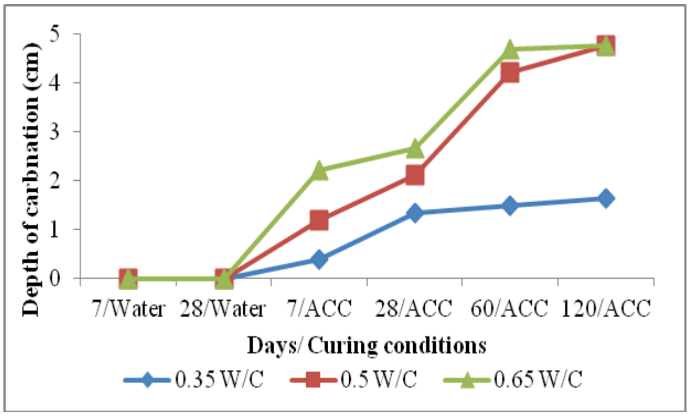

Figure 5. Variation of depth of carbonation of accelerated carbonated concrete with time

4. Conclusions

Within the scope of this study, the following conclusions have been drawn.

i. The compressive strength of the concrete specimens subjected to accelerated carbonation curing has increased as the duration of exposure increased. The increase in the water binder ratios has decreased the compressive strength.

ii. Modulus of elasticity has increased with duration of exposure and decreased with an increase in water binder ratios.

iii. The depth of carbonation has had a sharp increase with the duration of exposure, i.e., as the exposure duration increased, the depth of carbonation has increased. Higher water binder ratios have shown high depths of carbonation. After 60 days of accelerated carbonation, the depth of carbonated zone has steadily increased unlike the steep rise for 60 days.

5. Acknowledgement

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6. References

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