

A Performance Based Approach on The Durability of Carbonated Concrete

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Abstract- In today's concrete, pozzolanic and cementitious elements play a vital role. Not only may pozzolanic or cementitious wastes from industries and constructions help to minimise environmental pollution and energy consumption in the building sector. As a result, the building industry is looking for new ways to create this common material. It may be divided into two categories. One option is to employ supplemental elements in concrete as a partial replacement for cement. Another option is to extend the life of an existing structure. For ecological, economic, and quality reasons, the use of supplemental cementitious materials, whether natural, waste, or by product, is becoming more common in cement making. Fly ash, discarded glass, silica fume, reclaimed concrete, blast furnace slag, red mud, and other materials are used in the design. Cement's contents appear to be identical to those of the primary oxides present in granulated blast furnace slag, SiO_2 , CaO , Al_2O_3 , and MgO . The effect of using granulated blast furnace slag instead of cement at various percentages on water absorption and sorptivity qualities was investigated in this study. The effects of using fly ash, rice husk ash, and ground granulated blast furnace slag on the water absorption and sorptivity characteristics of concrete with varied CO_2 exposure percentages and exposure hours are discussed in this study. The goal of this investigation was to see if concrete could be strengthened with 15 percent fly ash (FA) and rice husk ash (RHA), ground granulated blast furnace slag (GGBFS) as a partial replacement for cement to lessen carbonation effects. The experiments were conducted on concrete specimens with and without CO_2 exposure to measure durability features such as water absorption and sorptivity at the age of curing 28 days.

Indexed Terms- cementitious, carbonation, CO_2 , durability, pozzolanic materials, sorptivity, water absorption.

I. INTRODUCTION

For concrete constructions exposed to harsh conditions, durability is a crucial challenge. Many environmental factors have been shown to have a substantial impact on the long-term durability of reinforced concrete buildings. One of the key causes of building degradation is carbonation. Carbonation occurs when hydration products dissolved in pore water react with carbon dioxide in the air, lowering the pH of the concrete pore solution from 12.6 to less than 9, destroying the steel passive oxide coating and speeding uniform corrosion. Carbonation-induced corrosion can accelerate the formation of cracks and reduce the durability of concrete. Carbonation lowers the pH and dissolves the passive coating surrounding the steel, but it also appears to densify the concrete surface, lowering chloride ion permeability, surface porosity, and hence concrete sorptivity. Concrete durability may be affected by carbonation in both good and bad ways. Even a modest quantity of chloride into carbonated concrete accelerates the corrosion rate caused by the carbonation process. The diffusion coefficient of the hardened concrete is the most important element controlling carbonation. The rate of carbonation is regulated by CO_2 diffusion into the concrete pore system, with a CO_2 concentration gradient acting as the driving factor. The kind and amount of cement, the porosity of the material, the curing period, and the type and quantity of pozzolanic additives are all factors that impact diffusion rate. Furthermore, carbonation can alter various mechanical characteristics of concrete, including compressive strength, surface hardness, and resistance to aggressive agents. To investigate the effect of carbonation on the mechanical properties and

durability of concrete, researchers used compressive strength tests, splitting strength tests, electrical resistivity tests, rapid chloride penetration test (RCPT), open circuit potential method, and alternative current (AC) impedance method.

II. LITERATURE REVIEW

Carbonation is a common concrete deterioration that can be accompanied by more severe degradations. It is required to discover appropriate performance tests and indicators in order to transition from prescriptive requirements to performance-based specifications for durability using the comparable performance concept. The impacts of binder composition, aggregate type, and curing conditions were investigated using concrete mixes that met the specified binder content and water–cement ratios. Early drying, as well as cement substitution with low-calcium fly ash, had a negative impact on performance. Aggregates influenced real water content and curing in an indirect way. Because they exclusively characterise concrete compactness, porosity, gas permeability, and chloride diffusivity were proven to be unreliable markers of carbonation.[1]

As a performance test, an accelerated corrosion test is recommended since it is responsive enough and produces findings that are compatible with spontaneous carbonation in the investigated exposure settings. Another indication, based on the ratio of chloride diffusivity to initial CaO concentration, might provide relevant information for certain aggregates mixtures and curing circumstances since it considers concrete compactness and binder physicochemical characteristics.[2]

The influence of carbonation on the mechanical characteristics and properties of concrete was investigated in an experimental research.[3]

In this investigation, self-compacting concretes (SCC) with water/binder ratios of 0.40 and 0.36 and ordinary portland concretes (OPC) with water/cement ratios of 0.58 and 0.48 were utilised. To assess the parameters of concrete, compressive strength tests, splitting strength tests, electrical resistivity tests, rapid chloride penetration test (RCPT), equivalent circuit potential technique, and alternate current (AC) impedance

method were used. Carbonation may compensate for several concrete qualities such as compressive strength, splitting strength, electrical resistivity, and chloride ion penetration, according to test results.

Carbonation, on the other hand, accelerated the amount of corrosion of reinforcing steel in corrosion tests.[4]

Reinforcement corrosion is a primary cause of concrete structural degradation. Carbon dioxide interacts with hydrated cement in the carbonation process, destroying its alkalinity. This has an impact on the long-term durability of the concrete. Permeability, capillary suction, diffusion, and osmosis are all concrete transport qualities that have been found to have a major impact.[5] Carbonation is well acknowledged as a major cause of concrete reinforcing corrosion. However, it has a number of additional effects in addition to depassivating the steel. The influence of carbonation on the penetration and pore structure of concrete is investigated in this research. Among the most notable repercussions of this phenomenon is that it leads to false findings in routine durability testing.[6]

An evaluation of the various methodologies led to the selection of appropriate test protocols for measuring porosity and permeability.[7]

Wet and dry curing samples of two concrete mixes with varied water/cement ratios were made and subjected in a carbonated chamber for up to 140 days. The findings reveal that carbonation decreases permeability and porosity, and they also illustrate how much of a reduction there is. In low-quality concrete, the decrease was the largest.[8]

When compared to some other impacts of carbonation, the decrease in permeability is comparable to the decrease in electrical resistivity, which can also contribute to false test findings.[9]

The moisture content of concrete materials is influenced by the surrounding environment. An experimental examination of the effect of water absorption on the durability of concrete materials is presented in this work. In order to build a relevant link between them, a comprehensive analysis is also

offered. Variable curing conditions were used to make concrete specimens with different water absorption, and the findings showed that the curing condition has a substantial impact on the surface water absorption. Distinct curing conditions resulted in different microstructures, as seen by SEM pictures. Concrete samples were tested for compressive strength, permeability, sulphate attack, and chloride ion diffusion after 28 days of curing. As a result, there is no apparent link between surface and interior sorptivity and compressive strength.[10]

The findings also revealed that only surface water absorption was linked to concrete performance, such as permeability, sulphate attack, and chloride ion diffusion. Furthermore, both impermeability and resistance to sulphate assault were shown to be linearly related to surface sorptivity, with both correlation values above 0.9. Furthermore, the exponent relationship between chloride ion diffusion coefficient and surface water absorption has a greater correlation coefficient. Internal water absorption, on the other hand, did not appear to be related to durability factors such as impermeability, resistance to sulphate assault, or chloride ion diffusion.[11]

Weight and sorptivity variations were detected in ordinary Portland cement (OPC) concrete specimens that had been air-dried for 3.5 years, with weight and sorptivity modifications being stronger for samples with higher original sorptivity. Since this was attributed to surface zone carbonation, the porosity variations between end slices and the interior of cylindrical specimens from a different test series (aged 4 years) were measured, as well as the depths of carbonation. The porosity difference may be attributed, in order of significance, to (i) depth of carbonation, (ii) original sorptivity, and (iii) original sorptivity, according to sensitivity tests done on a neural network model (which reflects both the quality of the mix and the efficiency of curing), & (iii) whether the last slice was on the top or bottom (reflecting the direction of casting and compaction). Tests on existing structures revealed that sorptivity decreased with age and that (carbonated) surface sorptivities were lower than interior sorptivities, confirming that the reduction in sorptivity with age is due to surface carbonation, which occurs more frequently in and benefits surfaces of lower initial

quality. This suggests that carbonation may have mutually compensating effects on concrete durability in some cases.[12]

III. CARBONATION OF CONCRETE

Carbonation occurs when carbon dioxide reacts with concrete hydrates such as portlandite $\text{Ca}(\text{OH})_2$ and calcium silicate hydrates (CSH) to produce calcite CaCO_3 and water. The process of deterioration is now well understood, and models of dissolution front propagation, primarily in Portland cement pastes or concrete, are available. However, the recent development of performance-based concrete durability requirements highlights the need for appropriate indicators that can be applied to a wide range of binders and are reasonably straightforward to measure. The majority of experimental research has focused on the influence of compactness as a function of fluctuations in the water–cement ratio, which is a key parameter in concrete durability. In reality, however, concrete mixes are frequently created using the maximum water/binder ratio while altering other factors such as aggregate and binder types to meet regulations.

IV. CARBONATION AND DURABILITY OF CONCRETE

A. Corrosion is an electrochemical process in which charges flow (electrons and ions). Iron atoms lose electrons at active areas on the bar, termed anodes, and migrate into the surrounding concrete as ferrous ions.

A half-cell oxidation reaction, often known as the anodic reaction, is the name given to this process.

- 1) This first precipitated hydroxide has a proclivity for reacting with oxygen to produce higher oxides. Internal tension inside the concrete may be sufficient to produce cracking and swelling of the concrete cover when the reaction products react further with dissolved oxygen, resulting in increased volume.
- 2) The carbonation depth is just a few centimetres and cannot reach the reinforcement.
- 3) Protection from carbonation CO_2 – isn't required. Carbonation is minor and finally stops when concrete quality is high and it is shielded from the causes of concrete disintegration, with the depth

reached being known as the maximum carbonation depth.

- 4) The reinforcing layer has nearly attained carbonation. To prevent further development, carbonation protection is required. The protection provided by the passivation layer surrounding the rebar will be lost if carbonation penetrates deeper and reaches the reinforcing. When carbonation is stopped, the passivation layer's protection is restored, and further concrete degradation is controlled.
- 5) The majority of the reinforcement is in the concrete's already carbonated zone. Carbonation protection would be too late in this situation. Surface protection's main purpose is to keep the reinforcement from corroding. If the concrete has already been carbonated, the only way to avoid corrosion is to waterproof that as well.

V. TESTS FOR DURABILITY

Concrete's durability refers to its ability to withstand weathering, chemical attack, and abrasion while maintaining its desired engineering properties. Each of these different attacks could have a different nature, intensity, and mechanism. Sorptivity tests were performed to establish the durability qualities of concrete water absorption and sorptivity tests.

VI. EXPERIMENTAL INVESTIGATION

6.1 Water Absorption Test

The water absorption test as per IS 516 (1959) was carried out using cube specimens with dimensions of 150mm x 150mm x 150 mm as a control, and cubes with 15% replacement of fly ash, rice husk ask, and ground granulated blast furnace slag as a replacement of cement in the concrete cubes were casted, and the specimens were immersed in water for 72 hours and retrieved from the curing tank, and then weighed in a loading balance immediately after wiping the specimen Saturated surface dry specimens were baked for 48 hours at 100°C. After removing the specimens from the oven and determining the initial weight (W1), they were submerged in water for 48 hours. After removing the specimen from the water, it was left outside for one hour before being weighed (W2) and the absorption was computed using the method below to determine the permeability of mortar. The

percentage weight of water absorbed with conventional concrete and 15% percentage of replacement of admixtures like fly ash, rice husk ask and GGBS are shown below in the Fig.2 & 3.

$$\% \text{ Water absorption} = [(W2 - W1) / W1] \times 100$$

Where,

W1 = Oven dry weight of cubes in grams,

W2 = after 24 hours wet weight of cubes in grams.

Figure 1 shows the water absorption test under process.



Fig.1 Specimens used for Water absorption test

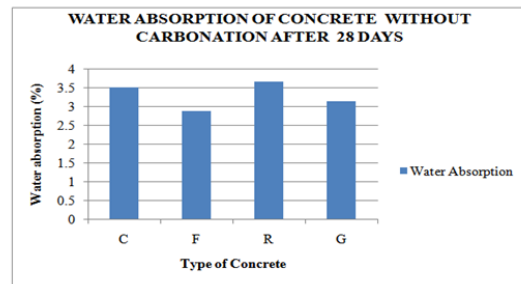


Fig.2 Water Absorption test results of Conventional Concrete without variation % of CO₂ exposure and Hours

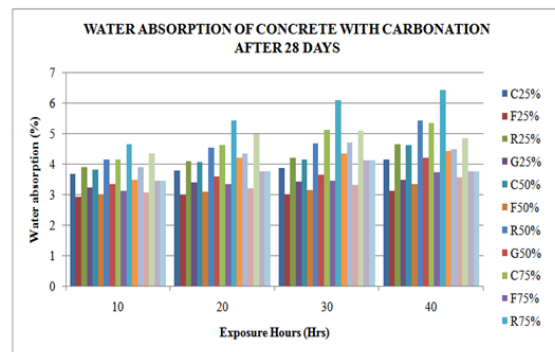


Fig.3 Water Absorption test results of different concrete after 28 days of curing with variation % of CO₂ exposure and Hours

6.2 Sorptivity Test:

Water infiltration into concrete pores under saturated conditions owing to capillary suction is referred to as sorptivity as per IS 516 (1959). The control cubes were 150 mm in diameter and 50 mm thick, while the cubes with 15% substitution of fly ash, rice husk ask, and crushed granulated blast furnace slag as a replacement of cement in the concrete cubes were cured for 28 days before being tested. The specimens were first dried in an oven at 105°C, then put in water as indicated in Fig.4 with the water level not exceeding 5 mm above the base of the specimen, and the flow from the peripheral surface was stopped by adequately sealing it with non-absorbent coating. The amount of water absorbed throughout a 30-minute period was determined by weighing the specimen on a top pan balance weighing up to 0.1 mg, wiping surface water off the specimen with a moistened tissue, and completing each weight operation in under 30 seconds. The specimen size 150 mm diameter and 50 mm thick control cubes and the cubes added with 15 % replacement of fly ash, rice husk ask and ground granulated blast furnace slag as a replacement of cement in the concrete cubes were cured for 28 days, it was taken for test. The test results of conventional concrete and 15% percentage of replacement of admixtures like fly ash, rice husk ask and GGBS are shown below in the Fig.5 & 6.

$$I = S.t^{1/2}$$

$$\text{Therefore, } S = I/t^{1/2}$$

Where;

S= sorptivity in mm, t = elapsed time in min.

$$I = \Delta W / A_d$$

$$\Delta W = \text{Change in weight} = W_2 - W_1$$

W_1 = Oven dry weight of cylinder

W_2 = Weight of cylinder after 30 minutes capillary suction of water

A= surface area of the sample through which water penetrated.

d= density of water



Fig.4 Sorptivity set up of control concrete

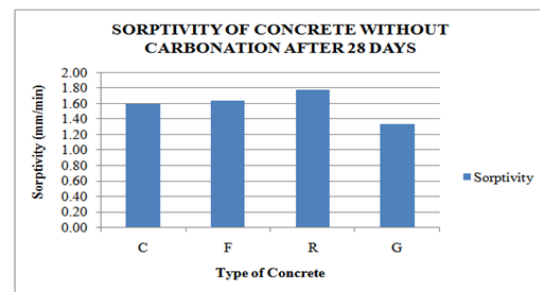


Fig.5 Sorptivity test results of Conventional Concrete after 28 days of curing without variation % of CO₂ exposure and Hours

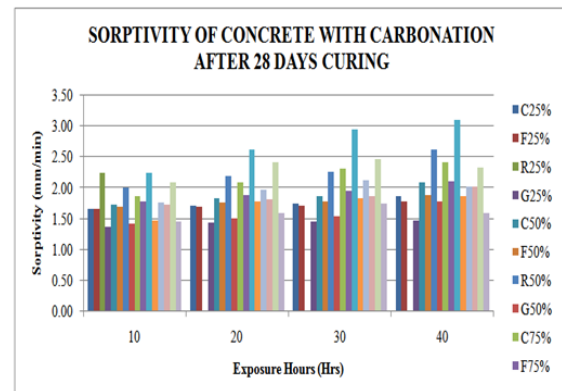


Fig.6 Sorptivity test results of different concrete after 28 days of curing with variation % of CO₂ exposure and Hours

CONCLUSION

The experimental research of both carbonated and non-carbonated concrete with and without admixtures is depicted in this work.

This research also discusses the role of CO₂ on concrete strength and mainly discusses how it affects the durability qualities of both carbonated and non-carbonated concrete specimens.

- The results of the water absorption and sorptivity tests showed that adding admixtures reduced water absorption and increased sorptivity, by enhancing the concrete's strength.
- The strength of concrete mainly decreases when it is exposed to CO₂ over a longer time span.
- By comparing the fresh properties, mechanical properties, and durability properties of the admixtures, it was found that the GGBFS is best suited in concrete to prevent carbonation.
- Thus, it was concluded that whenever the mixes were water-cured, they were less porous and more resistant to carbonation, as predicted.

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