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Determination of Flexural Strength of Concrete by Carbon Dioxide Curing

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ABSTRACT

The global gas emission is keeping on increasing for which cement industry alone contributes 5%. The enormous water is required for curing of concrete in construction industry which can effectively be used for various purposes. The accelerated carbonation curing shows a way to reduce these emissions in a very effective way by sequestering it in concrete elements. In this paper the effect of accelerated carbonation curing was reviewed on non-reinforced concrete elements (cubes) and reinforced concrete elements (prisms). The CO_2 curing showed 60% in strength of cubes and prisms, respectively when compared to water cured specimens. This early age strength through waste gas proves beneficial in terms of reducing in atmospheric pollution and saving the water which is a critical resource now-a-days.

Keywords: *Sodium silicate, Rice husk ash, Activated carbon.*

1. Introduction

Cement production alone contributes approximately 5% of global CO_2 emissions. The emitted carbon dioxide can be partially reused as a curing agent in concrete by initial age curing which results in the formation of thermodynamically stable compounds of calcium carbonates.

Concrete is known to possess the ability to absorb atmospheric carbon dioxide. The process of absorption of CO_2 into the concrete is called carbonation. Early-age CO_2 curing develops strength, increased surface hardness, and reduced surface permeability to water, as well as the reduction of efflorescence to concrete products. The reactions of carbonation between carbon dioxide and calcium compounds result in the formation of stable calcium carbonate as a permanent fixture.

Carbonation is the process by which CO_2 is absorbed in the concrete. Uncarbonated concrete units contain the typical cement hydration products of calcium silicate hydrates and calcium hydroxide. As concrete carbonates, calcium hydroxide and calcium silicates are converted to calcium carbonate, as shown in following equations:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

$$C_3S + 3CO_2 + H_2O \rightarrow C\text{-}S\text{-}H + 3CaCO_3$$

$$C_2S + 2CO_2 + H_2O \rightarrow C\text{-}S\text{-}H + 2CaCO_3$$

Carbonation curing requires only 4 to 8 hours of curing time under controlled conditions to get the strength which the conventional water cured concrete specimen require 28 days. This early age strength is because of the reaction of CO_2 gas with calcium hydroxide ($Ca(OH)_2$) and the bogeus compounds named tri-calcium silicate (C_3S) and di-calcium silicate (C_2S) to form calcium carbonate ($CaCO_3$) and calcium silicate hydrate gel (C-S-H). The gel imparts strengths to concrete and the latter helps in pore refinement of concrete. The reinforced concrete elements. undergo corrosion when placed in the corrosive atmosphere. This corrosion is prevented by placing an appropriate cover or protective coatings on reinforcement. This helps in protecting steel in acidic environment.

2. Literature Review

Vijaya Kumar & Seema [1], "Review on carbon dioxide curing of concrete". The experimental study on water cured and CO_2 specimens for compression strength were carried out. The results show that for M25 and M30 grade of concrete has achieved increasing value as comparing with 7days of water curing and the duration of 4 hour CO_2 curing. For M25 grade of concrete has achieved 70% of compression strength and M30 grade of concrete has achieved 65% of compression strength in the duration of 4hours of CO_2 cured specimens when compared to 28 days of water cured specimens.

Vijay Kumar et al. [2], "Effect of Carbon-Dioxide Curing on Concrete", The study is carried to evaluate the carbon dioxide cured concrete over traditional curing of concrete. Two mix designs M25 and M30 are considered for curing. Different samples were prepared and cured for both the cases. The periodical observation is done to find the compressive strength at 7 days to 28 days for normal cured 2 hours to 4 hours for CO_2 cured. The results show that CO_2 cured concrete achieves 76.28% target strength within 2 hours and normal cured 75.8% target strength in 7 days for M25. For both M25 and M30 grade concrete with water curing achieved compressive strength more than the target strength.

Santhosh Kumar et al. [3], "Mechanical Properties of Concrete when cured with Carbon dioxide". This paper summarizes the mechanical properties of concrete when cured in artificial CO_2 environment i.e. by using dynamic pressurized CO_2 curing chamber and Dry ice. The research includes designing a concrete mix of M25 grade as per IS 10262:2009. In this research, the effect of carbonation was analyzed by CO_2 curing and dry ice curing. The experimental study on water cured, CO_2 cured and dry ice cured specimens for compressive strength, split tensile strength and flexural strength were carried out. The results show that 90% of compressive strength was achieved for 8 hours of CO_2 cured specimens when compared to 28 days of water cured specimen.

Mohd Tanjeem Khan et al. [4], "Curing of Concrete by Carbon Dioxide". This paper summarizes a recent study on optimization of concrete and the flue gas carbon dioxide collected from cement kiln can be beneficially utilized in concrete production to reduce carbon emission, accelerate early strength, and improve durability of the products. In reference to cement content, carbon uptake in 4-hour carbonation reaches 28 days strength achieved by conventional curing method.

Rakesh & Kavitha [5], They have studied use of CO_2 mitigation responses in concrete and cement products is one of the possible technologies as carbon sink through the fast curing in early age, used bamboo fibre was a replaced material for cement as 1% with the water cement ratio was 0.53. in order to find out the Carbonation curing, they comparing with fiber and without fiber. They have tested both water curing and carbon curing for 3,7,14.21.28 days, finally they have got more strength in with fiber used specimen and also get more strength in CO_2 cured specimen when comparing conventional cured specimen.

Zhen Li et al. [6], "The Performance of Carbonation-Cured Concrete". The research shows that carbonation-cured concrete has several mechanical and durability properties that are better than those of moisture-cured concrete. However, many properties of carbonation-cured concrete have not yet been studied. In this research, carbonation-cured concrete was prepared by pre-curing, carbonation curing, and then moisture curing. The compressive strength, CO_2 uptake, pH value, chloride ion permeability and abrasion resistance of the carbonation-cured concrete were investigated. Results showed that the compressive strength of carbonation-cured concrete was more than 10% higher than that of moisture-cured concrete at the same age; a steel bar is stable in carbonation-cured concrete; and carbonation-cured concrete exhibited better abrasion resistance and chloride ion permeability than that of moisture-cured concrete. The optimization of pore structure and improvement in the micro-hardness are the reasons for the improved chloride ion permeability and abrasion resistance of carbonation-cured concrete.

Vibhas Bambroo et al. [7], "Study on potential of carbon dioxide absorption in reinforced concrete beams". In this research the effect of accelerated carbonation curing was checked on non-reinforced concrete elements (cubes) and reinforced concrete elements (prisms). The 100mm x 100mm x 100 mm cubes and 150mm x 150mm x 1200mm prisms were cast. They were CO_2 cured for 4 and 8 hours and were tested for compressive strength and flexural strength test. The CO_2 curing results showed 27.7% and 1.8% increase in strength of cubes and prisms, respectively when compared to water cured specimens. This early age strength through waste gas proves beneficial in terms of reducing in atmospheric pollution and saving the water which is a critical resource now-a-days.

Ming-Gin Lee et al. [8], this paper summarized the CO_2 cured cylinder with 3 different sizes and the compressive strength with various curing timings and finally compared with 28 days of water cured cylinder with different sizes. The results of CO_2 cured concrete ratio or longer CO_2 curing time produced higher early strength. The concrete specimen mixed with CO_2 under 0.2 to 0.6 Mpa pressure produced lower compressive strength the results show like cylinder has got higher compressive strength when comparing conventional cured blocks.

Gowsika & Balamurugan [9], they have concentrated to assess viability of various curing methods and study the impact of atmosphere on the quality properties of cement. The examples were thrown for the testing of compressive quality at 7, 14 and 28 days of relieving. Individually they were utilizing seven restoring techniques, to be specific Ponding, Immersion, Oven relieving, Air Drying, calcium chloride (random), Membrane relieving and Pack (Plastic sheeting) restoring. Test outcomes demonstrate that water restoring quality was improved up to 26.67% than film and shows 93% of traditional relieving. All through this investigation it is done over the solid has enormous impact on its quality properties on various techniques for restoring.

Prerna Tighare [10], this paper says that in the wake of experiencing the current writing on Contrast of impact of Hot water relieving, steam restoring and Usual restoring on quality of M20 evaluation of cement there is certain weakness of submersion strategy and to conquer this inadequacies the current exploration exertion targets considering the blend of inundation technique and different strategies for relieving like jute pack covering technique and plastic film technique.

The exertion will be ready to recreate the ground condition in lab. The examination looks to evaluate the impact of various restoring techniques on compressive quality of cement and cement ought to be relieved by best restoring strategy to accomplish a superior compressive quality. The current examination targets joining inundation strategy with damp covering, with utilization of restoring compound and plastic sheeting water prerequisite for 7 days, for example submersion relieving joined with these is proposed to be determined.

Ajay Goel et al. [11], this investigation to assess viability of various restoring strategies and study the impact of atmosphere on the quality properties of cement. Diverse restoring strategies in particular ponding, jute sack relieving, single layered film restoring, twofold layered layer restoring and air restoring are considered to examine the impact of various techniques for relieving and atmosphere on the nature of cement. Solid examples were tried subsequent to restoring of 3 days, 7 days and 28 days. Relieving compound was showered following expulsion from moulds and in the event of the twofold coat the subsequent coat was applied after 5 min of utilization of first coat. Standard Portland concrete of 53 evaluations fulfilling the prerequisites of IS: 12269-1987 with 28-days compressive quality of 58.5 Mpa is utilized. Blend configuration was finished focusing on M60 grade concrete according to ACI guidelines. Restoring might be applied in countless behaviour and the most fitting methods for sacking might be absorbed by the growth technique. Result got the expansion in quality up to 85 to 90% of ponding.

Don MacMaster & Oscar Tavares [12], "Carbon Sequestration of concrete masonry Units". Early-age carbonation curing of concrete products results in improved strength, increased surface hardness, and reduced surface permeability to water, as well as the reduction of efflorescence. Carbonation reactions between carbon dioxide and calcium compounds result in permanent fixture of the carbon dioxide in thermodynamic stable calcium carbonate. The moisture content, relative humidity, and temperature profile of the hydrated system have considerable and important influence on the rate and ultimate extent of carbonation. During carbonation, CO_2 penetrates the surface of concrete and reacts with cement hydration products namely, calcium hydroxide and calcium silicate hydrates to form carbonates. This study quantifies carbon sequestration levels in concrete masonry units using various curing methodologies. The test results of a dynamic pressurized CO_2 curing chamber and normal ambient CO_2 pressure at various concentrations levels are compared to traditional kiln curing procedures. Early compressive strength profiles for 30% CO_2 cured concrete masonry units (CMUs) are equivalent to 100% CO_2 cured CMUs and exceed the traditional kiln-cured compressive strengths. Carbon sequestration reduced water requirements by 20% for optimum strength performance and provided water conservation opportunities.

Hilal El-Hassan & Yixin Shao [13], "Carbon Storage through Concrete Block Carbonation Curing". The effect of initial curing on carbonation curing of lightweight concrete masonry units (CMU) was examined. Initial curing was performed from 4 to 18 hours at a relative humidity of 50% and temperature of 25°C. Based on cement content, four-hour carbonation curing allowed concretes to uptake 22% to 24% CO_2 with initial curing and 8.5% without initial curing, while prolonged 4-day carbonation recorded an uptake of 35%. Carbonation curing can replace steam curing in CMU production to accelerate hydration and recycle cement kiln CO_2 in a beneficial manner.

Zhan et al. [14], "Experimental study on CO_2 curing for enhancement of recycled aggregate properties". In this paper, the results of an experimental program on studying the use of a carbonation process to enhance the properties of recycled aggregates are presented. Hardened concretes prepared by using different water-to-cement ratios in the laboratory, were crushed to produce recycled aggregates with different particle sizes. Before and after the laboratory carbonation process, the physical properties of the recycled aggregate, including water absorption and density were determined. The extent of CO_2 curing of the recycled aggregate was quantified by assessing the carbonation percentage of the aggregates. Carbonation resulted in reduction in water absorption values and increase in density and these showed that the properties of recycled aggregate were improved. The factors influencing the

CO_2 curing process, including curing time, particle size and moisture contents of the recycled aggregate, were investigated.

James [15], This examination reports the all out of 72 3D shapes of blend proportion 1:2:4 were explored subsequent to exposing them to different relieving circumstances, the outcomes acquired validated ordinary compressive eminence qualities for 7, 14, 21 and 28 days, shift with restoring techniques, the outcomes show that ponding had the most raised compressive excellence and the its thickness.

Yixin Shao & Xiaolu Lin [16], "Early-Age Carbonation Curing of Concrete Using Recovered CO_2". Using CO_2 of 99% purity to simulate CO_2 recovered from cement kiln flue gas, early-age CO_2 curing of dry-mix, lightweight, and normal weight concrete mixtures was evaluated. Specimens prepared in the laboratory were evaluated for carbon uptake, strength gain, pH, and chemical analysis. Manufactured concrete pavers were evaluated for durability. The authors believe that early-age carbonation curing can provide permanent carbon storage and improve short-term and long-term performance of concrete.

Teramura & Isu [17], they have used ALC as clasp in the CO_2 development. The excess ALC were sieved by 1.8 mm and a short time later handled by a ball-plant for sixty min. The liquid to solid extent was in the extent of 25 to 65% by the weight. The wet excess ALC was compressed in the shape under l0MPa strain to outline the plate 100mm x l00mm x 12mm. This technique they were used 100% centralization of CO_2 and gas force from air to 0.4 MPa. They in like manner test air carbonation by using 3% CO_2 obsession and 3% of pneumatic stress. The carbonated models were drying in an oven at 60°C for the duration of 24 hours afterward carbonation. Three-point bowing test were used for those plates and the cross-head pace of 0.2 mm/min.

Simatupang & Habighorst [18], they have advanced an industrialized method for cement particle boards in order to decrease the pressing duration. Wood elements were saturated in the water, then additional to Portland cement and mixed well. Different stainless steel equipment was used to do quick CO_2 curing.

The press sleeve to take up the moist wood/cement mixture and the piston to condense the mortar. The compaction pressure was 4 MPa. Press plate used for CO_2 was injected top and bottom into the specimen. The w/c ratio was varied. And that is from 0.1-0.6, account the water. Better results were obtained.

Bukowski & Berger [19], they have tried of University was used the C_2S, CS and Portland concrete as clasp to examine CO_2 gas soothing. The extent of clasp to sand was composed by weight, and the extent of water to sheet was by mass was 0.202, 0.206 and 0.191 for C_2S, CS and ordinary concrete, independently.

They have used hand mixing for nearly 3min and a while later trodden at 26 MPa load into 15.9mm in expansiveness loads around 20mm height. After compaction was done, the chamber was kept in a container by 95% relative tenacity for 2 hours earlier carbonation. They have furthermore used calcium silicate powders for carbonation with a comparable water and cement extent as the preservationist mortars.

Shi & Wu [20], "Studies on some factors affecting CO_2 curing of lightweight concrete products". This paper deals with the effects of several factors, such as CO_2 pressure, curing time, water-to-cement ratio and continued curing after CO_2 curing on temperature profiles, CO_2 curing degree and strength of concrete. Results indicated that the accelerated reactions between CO_2 and cement minerals happen mainly during the first 15 min regardless of CO_2 pressure and pre-conditioning environment. CO_2 curing degree and strength increased as the CO_2 pressure and curing time increased. The concrete specimens should have a water-to-cement ratio greater than certain value so as to facilitate the moulding of concrete products and to achieve a high CO_2 curing degree. CO_2 cured specimens will continue to gain strength due to the hydration of cement minerals unreacted during the CO_2 curing if the specimens are kept in moist environment.

Zhang et al. [21], "Carbonation Curing of Precast Fly Ash Concrete". The feasibility of carbonation curing of precast fly ash concrete is studied. If fly ash concrete can be produced by carbonation curing, the carbon footprint of the products can be significantly reduced. In this paper, the relationship between carbonation reaction and pozzolanic reaction was examined. After carbonation curing with different duration and fly ash content, the cement reaction degree was estimated through the equivalent non-evaporable water content, and the fly ash reaction degree was analyzed through a selective acid dissolution test. It was found that the pozzolanic reaction of fly ash in a fly ash–ordinary portland cement (OPC) system was hindered by early carbonation reaction. The higher the early carbonation degree, the lower the pozzolanic reaction of fly ash. In addition, fly ash-OPC paste was more reactive with carbon dioxide than plain cement paste.

Therefore, controlled carbonation at an early age is necessary to trade off the carbon emission reduction with performance gain. The study shows that if fly ash content is limited to 20% of cementitious material and carbonation curing duration is not to exceed 12 h, fly ash concrete can be produced with higher early strength, comparable late strength, better durability performance, and a carbon emission reduction of 36%. After subsequent hydration, carbonated fly ash concrete can have a pH value comparable with the hydration reference and can be used in precast concretes with steel reinforcement.

3. Conclusion

After studying the journal papers, many researchers are said that the strength of concrete specimens is 60 percent increase in strength than water cured specimens, respectively.

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Competing Interests Statement

The authors declare no competing financial, professional and personal interests.

Consent for publication

Authors declare that they consented for the publication of this research work.

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