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Curing of Concrete by Carbon Dioxide

Mohd Tanjeem Khan[1], Khan Rahim Saud[2], Karadia Ashraf M.Irfan[3], Shaikh Ibrahim[4]

[1,2,3] UG Student, Civil Department, Jamia Institute of Engineering & Management Studies, Akkalkuwa, Maharashtra, India
[4]Assistant Professor, Civil Department, Jamia Institute of Engineering & Management Studies, Akkalkuwa, Maharashtra, India

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Abstract - *Carbon dioxide (CO_2) is the predominant greenhouse gas resulting from human industrial Activities. A significant fraction of CO_2 discharged into the atmosphere comes from Industry point sources. Cement production alone contributes approximately 5% of global CO_2 emissions. This emitted carbon dioxide, however, can be partially recycled into concretes through early age curing to form thermodynamically stable calcium carbonates. The carbonation reaction between carbon dioxide and appropriate calcium Compounds results in permanent fixation of the carbon dioxide in a thermodynamically stable calcium carbonate. Carbon dioxide and water can be found in almost every environment and thus all concretes will be subjected to carbonation. 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.*

Key Words: **CO_2 utilisation, Carbonation Curing, Early Curing.**

1. INTRODUCTION

Earth's atmosphere acts like a blanket to absorb the sun's solar radiation, which heats the earth's surface and keeps it warm. Due to human and anthropogenic activities, the increasing carbon dioxide gas concentration in the atmosphere is currently disturbing the natural composition of the CO_2 greenhouse gases. Furthermore, some argue that the atmospheric CO_2 increase is causing a global temperature increase. As the temperature increases, more water vapour, which is also a greenhouse gas is released into the atmosphere. Most scientists agree that the earth is warming at a faster rate than at any time in the last 10,000 years, and that this warming is caused by increasing amounts of carbon dioxide and other greenhouse gases in the earth's atmosphere. There are many potential effects and consequences expected to result from a rise in global temperature. The ocean water level is expected to rise and threaten many coast cities with floods due to melting glaciers, melting Antarctic ice caps, and the thermal expansion of the ocean water. In the tropic zone, the desertification is expected to be a prevalent trend. The impact of global warming on people and nature is severe, and will disturb the viable and comfortable environment. Carbon dioxide is the dominant greenhouse. Finding beneficial uses of as-captured or recovered CO_2 is challenging and critical to greenhouse mitigation. One potential technology is to use the captured or recovered CO_2 as a curing agent in production of carbonated concrete products. The process is called curing carbonation. Carbon dioxide is the most influential greenhouse gas, so the current research of mitigating technologies was focused on the CO_2 emissions and utilised the recovered CO_2 and collected waste gas from cement kiln could be used as curing agent to concrete.

1.1 Carbonation Process

The curing carbonation process is different from weathering carbonation that naturally occurs in hardened concrete. Weathering carbonation is well known and has been extensively investigated. In weathering carbonation, hydration takes place first when cement is mixed with water and is followed by natural carbonation, a reaction between the hydration products and the atmospheric carbon dioxide. The weathering reactions of major hydration products (calcium hydroxide and calcium-silicate-hydrates) are:

$$Ca(OH)2+2C02 \rightarrow CaC03+ H20 \quad (1)$$

$$3CaO+2Si02 +3H20 +3C02+\rightarrow 3CaC03 +2Si02+3H20 \quad (2)$$

Weathering carbonation of concrete is a slow process, and becomes a concern in steel reinforced concrete structure since the carbonation decreases concrete pH, which helps initial corrosion of reinforcing steel. The underlying principal is that the cement compounds C3S and C2S are instantaneously carbonized into calcium carbonate and silica gel once cement is mixed with water and exposed to the carbon dioxide gas. Curing carbonation is an accelerated curing process that injects CO2 gas into the curing vessel at room temperature, diffuses the carbon dioxide into the fresh concrete under low pressure, and transforms the gaseous CO2 into solid calcium carbonates (CaCO3).

$$3CaO.Si02+3C02+xH2O \rightarrow Si02.xH20+3CaC03 \quad (3)$$

$$2CaO.Si02+2C02+xH20\rightarrow Si02.xH20+2CaC03 \quad (4)$$

Equations (3) (4) are the summation of various reactions, e.g. the dissolution of C02(g) to C02(aq); the reaction of C02(aq) with H2O resulting in the production of H+ and HCO3" ions, and subsequent reaction of the H+ ions with the 3CaO«Si02 and 2CaO«Si02 to release Ca2+(aq) and the subsequent reaction of Ca2+ and HCO3" to produce CaC03(s), which forms the basis for the CO2 sequestration [Bukowski, 1978]. Since curing carbonation is a highly exothermic reaction, concrete is solidified at a much faster rate than by steam curing at 75°C. The carbonation products are primarily calcium carbonates and silica gel (Eqs. 3 & 4). For applications without reinforcing steel, the carbonated concrete products can increase performance with respect to achieving strength, durability and stable dimensions, due to the near-complete depletion of calcium hydroxide. It is most suitable for concrete products, such as blocks and cement boards.

2. LITERATURE REVIEW

Carbonation cementitious system is not a new process; its origins can be traced back thousands of years. Humans have used alkaline earth hydroxide cement and mortar as a binder to build structures, which harden due to their reaction with the carbon dioxide In the atmosphere. Because of the low concentration of CO2 in atmosphere and low Pressure of CO2, the diffusion of CO2 into mortar is very slow. This results in a slow strength development of the mortar. Since 1970's, researches were conducted in an Attempt to understand the carbonation mechanisms and their applications in fast curing of Cement and concrete products.

2.1 Compacted calcium silicate mortars and powders on exposure to CO2

Bukowski and Berger [1978] of University of Illinois used the C2S, CS and Portland cement as binder to research carbon dioxide gas curing. The ratio of binder to sand was one to one by weight, and the ratio of water to binder was by weight was 0.202, 0.206 and 0.191 for C2S, CS and Portland cement, respectively. The mortar was mixed by hand for approximately 3 minutes and then compacted at 26MPa pressure into 15.9mm in diameter cylinders approximately 20mm in height. After compaction, the cylinder was kept in a vessel with 95% relative humidity for 2 hours before carbonation. They also made calcium silicate powders for carbonation with the same water to cement ratio as the compact mortars.

2.2 Rapid carbon dioxide curing for wood-cement composite

Simatupang and his research group [1995] developed a manufacturing process for cement particleboards in order to reduce the press time. First the wood particles were soaked with water, then added to Portland cement and mixed until it became a homogeneous mixture. A special stainless steel apparatus was used to do rapid CO2 cement curing. It included three parts: the lower part with a perforated disc and a three way valve to apply either vacuum or carbon dioxide pressure, the press sleeve to take up the moist wood/cement mixture and the piston to compress the mortar. The mixture was put into the sleeve and compacted slightly by piston. The compaction pressure was 4 MPa. After the vacuum of 0.1 Bar, carbon dioxide was injected into the specimen. A special press plated was designed for the C02 injection during compression. This press plate was installed on both sides of the specimen, so the top and bottom surfaces of each specimen could be carbonated. The water to cement ratio was varied from 0.1 to 0.6, which took into account the water absorption of wood. The diameter of specimen was 50mm and the thickness was about 12.4mm.

2.3 Carbon dioxide curing of waste concrete

Teramura and Isu [2000] interested in the use of waste autoclaved lightweight concrete (ALC) as binder in carbonation process. The waste ALC were crushed and sieved to under 1.8 mm and then pulverized by a ball-mill for 60 minutes. The water to solid ratio was in the range of 25-65% by weight. The wet waste ALC was compacted in the mold under lOMPa pressure to form the plate 100 x lOOx 12 mm. The carbonation process used 100% concentration CO2 and gas pressure from atmospheric to 0.4 MPa. They also experimented atmospheric carbonation by using 3% CO2 concentration and atmospheric pressure. The carbonated samples were dried in an oven at 60°C for 24 hours after carbonation. These plates were tested by a three point bending test, at a cross-head rate of 0.2mm/min.

3. METHODOLOGY

The closed system is appropriate for the direct use of as-captured flue gas without separation. The flue gas, containing 14% CO2, was collected from a cement kiln. To work with low concentration flue gas, a cyclic injection process was developed. The flue gas was injected into the chamber at a gauge pressure of 500 kPa (72 psi). The higher gas pressure is used to ensure that sufficient carbon dioxide is available for reaction. The chamber's inlet valve is then closed to permit the reaction to take place over a designated period of 30 to 40 minutes. Since the airtight system is closed after pressurization, both the CO2 concentration and the gas pressure in the chamber will drop as the concrete absorbs CO2. After the designated period of time, the residue gas is released to the atmosphere through a water tank and flue gas is again injected into the chamber for a second cycle. Typical pressure and temperature curves of cement paste compacts subjected to seven cycles of flue gas carbonation with a 30-40 minute time period per cycle over a total of five hours. The cement compacts with W/B of 0.15 were press formed at 8 MPa (1.2 ksi). Since the reaction between cement and flue gas CO2 is a carbon consumption process, it eventually reduces the gas pressure and CO2 concentration in the chamber.

Therefore the pressure drop and concentration reduction in each cycle are indicative of the carbon uptake process. The curing process should be terminated when the pressure and concentration are seen to remain constant, which would indicate that no further carbonation reaction is occurring. This can be considered a pseudo-dynamic system with the flue gas having a measureable residence time in the chamber. The gas pressure and time period of each cycle should be determined by the scale of production. In this process, carbon capture and sequestration are effectively combined into a single step with useful concrete products serving as the sequestration medium. In comparison to pure gas carbonation, longer reaction times are required for flue gas carbonation due to the lower CO2 concentration and lower reaction efficiency.

4. ACTUAL WORKING PROCEDURE

[1] Firstly take all the material, equipment or necessary things i.e. cement, sand, aggregate, water, concrete mould(150mm X 150mm X 150mm), carbon dioxide cylinder, air tight vessel(CO2 curing tank/box).

[2] Cast concrete blocks of mix M20 by inserting the concrete into concrete mould, remove the mould after 24 hours.

[3] It's time to construct the air tight vessel (or box) for CO2 curing.

[4] Place 3 concrete blocks into water curing tank, 3 into CO_2 air tight container and place 3 into normal room(for air curing).

[5] Close the CO2 curing container with cap and stick tape for no chances of any leakage of CO2 gas.

[6] Open the valve of CO2 cylinder to inlet the CO2 gas (for 2.5 hours).

Fig – 1 : Final Setup

[7] After 2.5 hours close the valve and leave the container for 4 hours.

[8] The curing of concrete cubes are done by absorbing the CO2 gas.

[9] Remove the tape and open the container.

[10] Compression test is done on concrete cubes for check the compressive strength of CO2 curing concrete cube.

Fig - 2 : UTM Machine Setup

[11] After 28 days, we check the compressive strength of water curing and air curing concrete cubes.

Fig – 3 : Failure of Concrete Cube

[12] Compare all three types curing concrete cube.

5. TEST AND RESULTS

The compression strengths of carbonated cubes were evaluated with UTM machine and the load rate was constantly 0.5mm/min till failure.

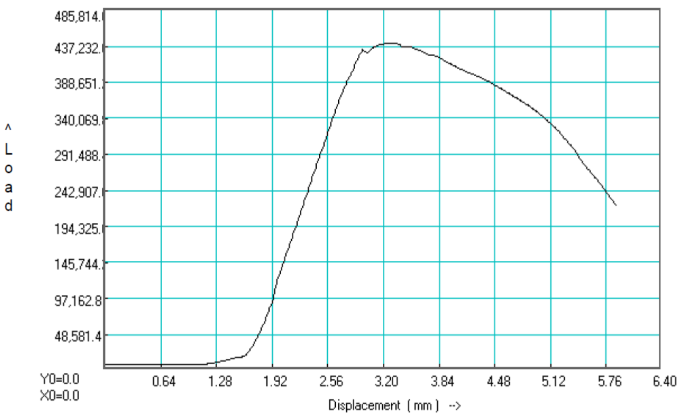

Chart – 1 : Graph Load vs Displacement

Results shows that the 4 hours curing by CO_2 of concrete block gives a mean strength of 19.5 MPa for M20 mixture of concrete. Since M20 Mixture Concrete gives 20 MPa compressive strength after 28 days of curing in water by conventional method.

6. ADVANTAGES AND DISADVANTAGES

6.1 Advantages:

[1] Rapid strength achieve due to use of CO_2 gas.

[2] $CaCO_3$ present in cement is unstable so use of CO_2 gas stables the $CaCO_3$, results in binding of cement to other member of concrete.

[3] Carbon is a component of increment of global warming, so use as curing agent for concrete results use of CO_2 and reduces the carbon element.

[4] Only 4 hours curing is sufficient, results rapid strength.

6.2 Disadvantages:

[1] Cannot used for RCC structure.

[2] The blocks, cardboard of concrete must place in environment of CO_2.

[3] The reinforcement bar provided in RCC structure corroded due to CO_2.

7. CONCLUSIONS

Feasibility of carbon dioxide uptake by concrete products through early age curing was studied. The following conclusions can be drawn:

[1] It is possible to carbonate the CaO-based cementitious materials in four hours to fast produce concrete building products with sufficient strength and certain amount of CO2 uptake. In general, higher CO2 concentration, longer carbonation time, higher CO_2 pressure can produce stronger products and promote more CO_2 absorption.

[2] The continuous CO_2 supply method proved to be technically effective and practically feasible in full scale concrete production using carbonation curing. The continuous CO_2 supply in carbonation process compensated the CO_2 diminishing automatically and promoted the CO_2 absorption by concrete to the maximum.

[3] Portland cement seemed to be the best binder for CO_2 absorption for both mass gain and strength development. Ladle slag and ground waste cement were not good for strength, but absorbed certain amount of the carbon dioxide gas. A hybrid system to blend cement with slag or waste cement would be efficient for carbonated concrete products to consume more CO_2 and maintain at least the same strength.

[4] Porosity is an important parameter for carbonation. Mortar mix with sand was more porous than the paste mix. The mortar mix developed similar strength as paste mix but gained a higher percentage of CO_2 uptake. It demonstrated the carbonation process could be an ideal curing method for concrete block production because of its porous nature of the product. Compared to the currently used steam curing, carbonation dose not require pre-setting period and thus can shorten the curing time substantially.

[5] The presence of water in carbonation is critical. The moist CO_2 could be another approach to improve the carbonation efficiency and requires a further investigation.

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