International Journal of Engineering & Technology, 7 (4.20) (2018) 382-385

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Utilization of Pervious Concrete in CO_2 Capturing to Control Environmental Impact of Portland Cement

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Abstract

The cement industry is a main producer of greenhouse gases that is responsible for 5–7% of CO_2 emissions. Therefore, it is important to find a method to reduce the concentration of this gas in the environment especially in places such as tunnels. This work aims to use pervious concrete to capture CO_2 from the environment and transform it to calcium carbonate inside its matrix. The pervious concrete exposed at 7, 14, and 28 days age to 25 and 50% concentration of CO_2 for a period of 2 and 4 hours to study the extent of carbonation inside this concrete. In addition to that, the effects of carbonation on compressive strength, weight change, CO_2-uptake and change in permeability were studied. The results showed that higher concentration of CO_2 and longer exposure periods caused deeper penetration of carbonation. The maximum recorded CO_2 uptake by pervious concrete occurs when it was exposed to higher CO_2 % and longer duration of exposure at the age of 7 days.

Keywords: *carbonation depth; CO_2 up-take; permeability; pervious concrete.*

1. Introduction

Carbon dioxide, CO_2, is one of the most important gases in the classification of greenhouse gases, which has a significant impact on the atmosphere and global warming. Cement plants alone produce about 5 - 7 % of the world's total carbon dioxide emissions [1]. One solution to reduce this gas is to recycle it in industries or to involve it in other reactions. Carbon dioxide reacts with calcium hydroxide $Ca(OH)_2$ in concrete to produce calcium carbonate $CaCO_3$ according to the following reaction:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

This reaction accelerates the gaining of strength. The applications used for this reaction are the production of bricks, blocks, cement board, precast concrete slabs and others [2].Thus can be satisfied by injection of CO_2 gas into a sealed chamber at 25-65C° temperature, diffuses the carbon dioxide into the fresh concrete under low pressure (0.83 MPa) [2]. The process of transferring calcium hydroxide $Ca(OH)_2$ in concrete to calcium carbonate $CaCO_3$, need moisture and system of pours and that can satisfied by using porous concrete.

Pervious concrete has many benefits, including absorbing as much surface water as possible, reducing runoff quantity and converting it into groundwater, thus reducing surface runoff. The porous concrete must be functioning designed in accordance with the hydraulic design in order to be achievement its design for hydraulic conductivity or permeability and to take full advantage of the surface water and store it as groundwater. The separate studies have regularly symbolized this data with an exponential relationship [3–7].

Pervious concrete is sensitive to the quantities of water and supplementary cementitious materials that are used to make a paste to forms a dense covering around aggregate particles. A mixture of pervious concrete contains little or no fine aggregate to create a significant void content. Therefore, this will create a highly permeable structure, due to this interlocked voids that make drains quickly. Normally, between 15 to 25 % voids are reached in the hardened concrete, where it depends on compaction and the category of the aggregates. The water flow rates through pervious concrete naturally are about 480 in./hr. (0.34 cm/s, which is 5 gal/ft2/ min or 200 L /m2/min), granting may be much greater. Both the high porosity percentage and low paste content will reduce compressive strength compared to conventional concrete mixes [8, 9]. The goal of study to experimental the behavior of pervious concrete how to effect when exposure to CO_2 gas? And how CO_2 uptake during time exposure?

2. Experimental Program

2.1. Materials and Mixes

The materials used in this work were sulfate-resisting Portland cement Type V conforming to ASTM C 150 [10] and IQS 5-1984 [11]. Local crushed gravel as coarse aggregate with maximum aggregate size of 12.5 mm and sulfate content of 0.073%, was used. A third generation high-range water reducer, with trade name Sika®ViscoCrete®-PC 20, was employed to control the rheology of the pervious concrete [12].

Table 1 lists the adopted mix proportions with some tested properties. These proportions were chosen according to common recommendations of international research work [13] and trial mixes.

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Table 1 pervious concrete mix proportions and properties

Materials				Properties					
Cement kg/m^3	Coarse Agg., kg/m^3	W/C ratio by wt.	HRWR by wt. of cement, %	Slump, mm	Compressive Strength, MPa, at age		Density, kg/m^3		Voids Ratio, % *
					7d	28d	fresh	28-d dry	
375	1800	0.34	0.5	80	13	28	1980	1920	17.6

*: Void ratio, % = 77 – 0.03 (fresh density, kg/m3) [13]

2.2. CO_2 exposure chamber

Figure 1 displays a schematic representation of the CO_2 exposure chamber. The system is sealed. It is fed with CO_2, under pressure of 140 kPa, from gas vessel. The pervious concrete specimens, at ages of 7, 14, and 28 days, were put inside the chamber then the gas was supplied to the chamber with concentrations of 25 and 50 %. The environmental chamber has a relative humidity reach to 50 % and a temperature of 40°C. The specimens were kept for 2 hours and 4 hours inside the chamber. Temperature and moisture were monitored by using thermocouples.

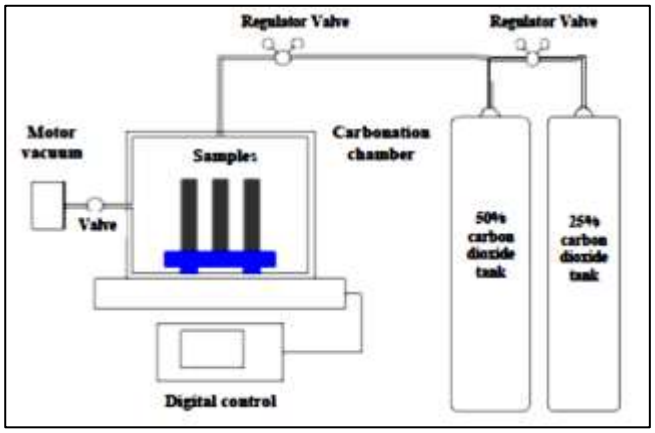


Figure 1 schematic representation of the CO_2 chamber

2.3. Testing Program

2.3.1. Slump test

The slump test was carried out in accordance to ASTM C 143/143M [14].

2.3.2. Compressive strength

Compressive strength test was conducted in accordance with BS 1881: Part 116 [15] on cubes with the dimensions of 100*100*100 mm. The average value of three cubes was adopted at each test. Tests were conducted at ages of 7 and 28days.

2.3.3. Carbonation depth

The depth of carbonation was inspected with phenolphthalein. Phenolphthalein is an indicator liquid that changes color from purple (high alkalinity) to white (low alkalinity) when pH drops below 8.5 in a water solution. The depth of carbonation represents the distance from the surface to the purple front that looks during visual measurement [16].

2.3.4. Weight change

This test measures the change in weight of specimens by mathematical method (change in weight divided by original weight) due to exposure to CO_2 at 25 and 50 % concentrations for 2 and 4 hours.

2.3.5. CO_2 uptake

Measurement of weight gain due to carbonation was used to calculate the CO_2 uptake by the concrete specimens through the exposure period [17]. Carbonation induced water loss was composed by absorbent paper which, added to the final mass. By considering the system as a sealed system, it was authoritative to include the vaporized water that was primarily inside the samples prior to carbonation.

$$CO2\ uptake\ (\%) = (Final\ mass + Mass\ of\ water\ loss - initial\ mass) / (Mass\ of\ cement) \quad (2)$$

2.3.6. Permeability

Permeability of pervious concrete carried out by using falling head permeability test method based on earlier studies [18, 19]. Cylindrical specimens, with diameter of 80mm and length of 150mm, were casted and tested before and after CO_2 exposure time. Figure 2 shows the diagram for test set-up.

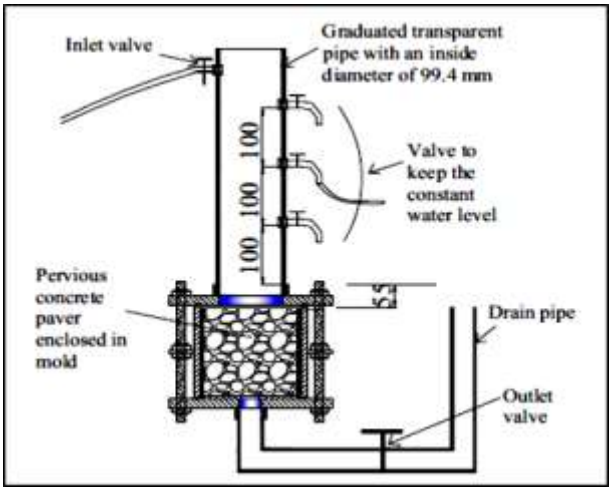


Figure 2 apparatus used for falling head permeability test [20]

3. Results and discussion

3.1. Compressive strength

Table 2 and Figure 3 indicate the effects of CO_2 concentration and exposure period on compressive strength of concrete. Results indicate that exposing specimens to 25% concentration of CO_2 for two hours causes insignificant increase in strength. The increase was 1.6, 2.1, and 1.3 % at 7, 14, and 28 days respectively. These percentages increased to 5.5, 9.7, and 2.8% when the concentration of CO_2 increased to 50%. In the same time, when increasing the time of exposure, of the 25 and 50% concentration of CO_2, from 2 to 4 hours, the strength increases in about 8.7, 8.7, and 2.2 % and 13.4, 12.3, and 56 % respectively with respect to the reference mix. This increase in strength is due to the formation of calcium carbonate $CaCO_3$ which have higher density than $Ca(OH)_2$ and densify the microstructure. The increase in compressive can be also from the exothermic nature of the carbonation reaction, which increases the heat and cause rapid solidification [21]. Results also show that subjecting concrete to CO_2 at earlier age, gives the higher increase in strength. This could be because of the progress of hydration that fill the pores and reduces the ingress of CO_2 to cement matrix [22, 23].

Table 2 effects of CO2 concentration and exposure period on properties of pervious concrete

Age of test, days	7				14				28				Reference mix		
Duration of exposure, hrs	2		4		2		4		2		4				
Percentage of CO_2 %	25	50	25	50	25	50	25	50	25	50	25	50	7 days	14 days	28 days
Compressive strength MPa	12.9	13.4	13.8	14.4	19.2	21.4	21.2	21.9	32.4	32.9	32.7	33.6	12.7	19.5	32
Carbonation depth mm(average)	4.145	4.65	4.595	5.18	3.785	4.13	4.12	4.625	2.426	3.88	2.85	3.14	-	-	-
Weight change after exposure %	0.156	0.253	0.244	0.287	0.09	0.083	0.082	0.093	0.052	0.067	0.083	0.095	-	-	-
CO_2 uptake%	0.8	1.33	1.6	2.13	0.53	0.56	0.85	0.91	0.26	0.53	0.62	0.88	-	-	-
Permeability (cm/s)	1.235	1.202	1.192	1.134	1.173	1.140	1.132	1.102	1.027	1.001	0.989	0.907	1.323	1.201	1.073

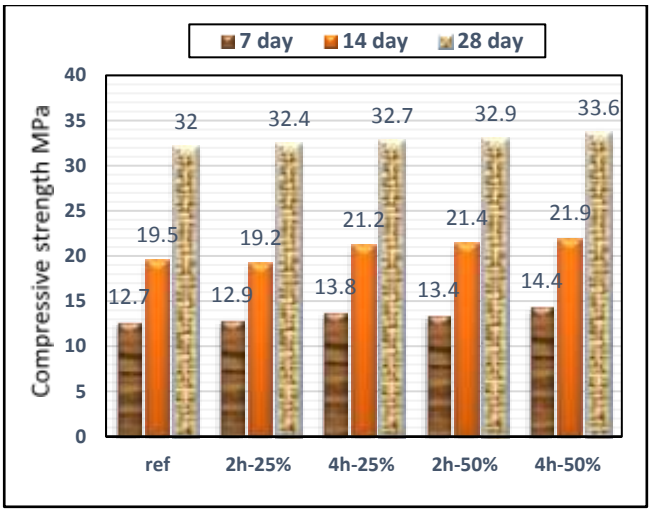


Figure 3 effects of CO_2 concentration and exposure period on compressive strength of pervious concrete

3.2. Carbonation penetration depth

According to Table 2 and Figure 4, the depth of carbonation measurement by digital calliper was conducted. The results show that the higher depth was 5.18 mm associated with the 50 % concentration and 4hrs exposure period at 7 days age. The lower value was 2.426 mm for 25 % of CO_2 and 2hrs at 28 days age. This reduction may be due to the filling of voids and pores with the products of the hydration of cement, that will reduce the ingress of CO_2 and its reaction with $Ca(OH)_2$ [22, 23].

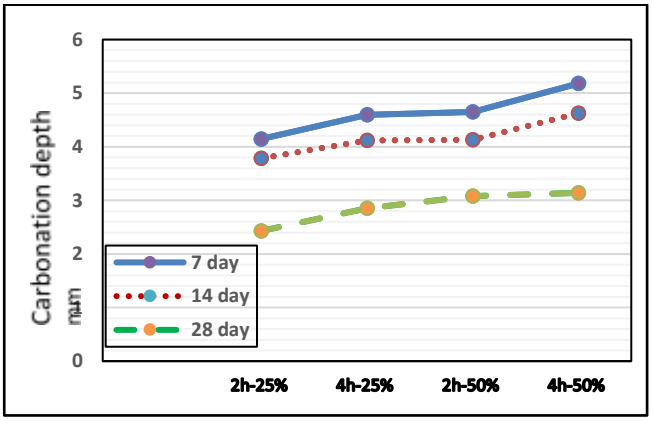


Figure 4 carbonation depth of pervious concrete for different concentrations and durations of exposure

3.3. Weight change

Table 2 and Figure 5 show that the increase in exposure time will increase the weight of concrete specimen than the original weight. The maximum percentage of weight increase in the 4hrs of exposure time and 50% of CO_2 gas concentration. The value reached 0.287%. The final product of reaction is calcium carbonate $CaCO_3$ which has higher density than $Ca(OH)_2$ [24].

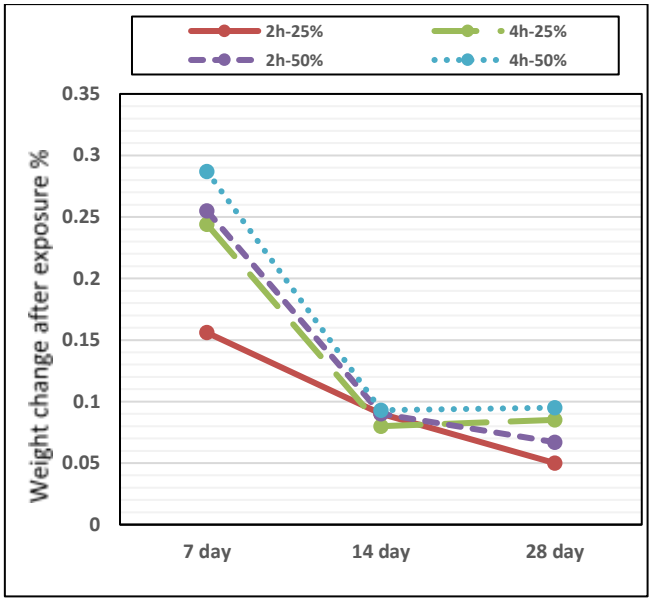


Figure 5 weight change of pervious concrete for different CO_2 concentrations and periods

3.4. CO_2 uptake

Table 2 and Figure 6 indicate the CO_2 uptake which was determined by weight increase from CO_2 exposure with the initial mass and dry binder of mixture as the formula (2), carbonated mass at the final including the loss of water, and the original weight of the dry binder. The CO_2 uptake is very low due to the loss of more than 25% of the mix water caused by vaporization by the exothermic reaction and heat rise during carbonation process [21]. The maximum significant of CO_2 uptake was when exposed to higher CO_2% and during long duration up to 2.13% in 4hrs at 7 days.

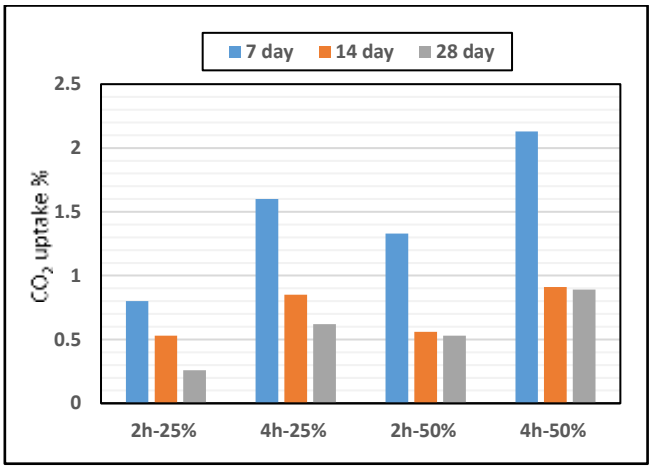


Figure 6 CO_2 uptake of pervious concrete for different CO_2 concentrations and periods

3.5. Permeability of pervious concrete

Table 2 and Figure 7 show the effects of CO_2 concentration and exposure period on permeability of pervious concrete. The results indicate that there is a significant reduction in permeability of concrete with exposure to CO_2 due to filling its voids by the products of carbonation, which indicate the ability of this type of concrete to sequestrate a significant amount of this gas in ambient environment leading to benefits to reduce the pollution from it. The lowest permeability found for concrete exposed to 50% of CO_2 for 4-hours at 28 days age to reach 0.907 cm/s which means a reduction in the permeability of reference mix by 31.4% and 15.5% for specimens

exposed to this environment at 7 and 28 days age. The permeability reduction occurs due to continuous hydration of cement and by transformation of calcium hydroxide to calcium carbonate which fills the pores in the cement matrix [22, 23].

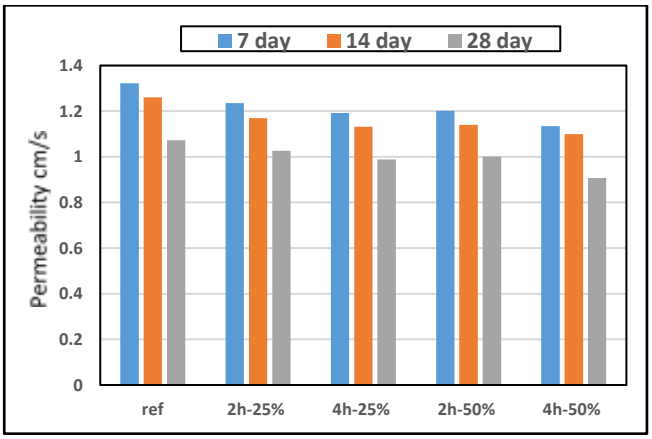


Figure 8 effects of CO_2 exposure concentrations and periods on permeability of pervious concrete

4. Conclusions

This study clarifies properties and behavior of pervious concrete exposed to different CO_2 concentration and exposure periods as follows:-

1- The carbonation depth reaches its higher value at earlier age of 7 days of 5.18 mm for 50 % concentration and 4hrs exposure period. The lower value is 2.426 mm in 25 % of CO_2 and 2hrs at 28 days age.
2- The higher increase in compressive strength will be achieved when exposing concrete to CO_2 environment at earlier age, due to the filling of pores with the products of CO_2 reaction with Ca(OH)2.
3- The increase in exposure time of CO_2 will increase the weight of concrete.
4- The maximum recorded CO_2 uptake by pervious concrete occurs when it will be exposed to higher CO_2 % and longer duration of exposure at the age of 7 days.
5- The large value of permeability for reference porous concrete is at earlier age due to higher voids and less hydration. The significant result obtained CO_2 gas at higher percentage of gas and high duration time.

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