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Effect of pre-conditioning on CO_2 curing of lightweight concrete blocks mixtures

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ABSTRACT

It is a common practice to use steam to cure precast concrete products and concrete masonry blocks after casting. Steam curing is an energy extensive process and contributes significantly to the production costs. This study investigated the effects of pre-conditioning on the CO_2 curing of lightweight concrete block mixtures. The results indicated that there was an optimum moisture loss at which the specimens demonstrated the highest strength and CO_2 consumption after CO_2 curing. However, the moisture evaporation rate had to be controlled so to avoid plastic shrinkage cracking. CO_2 curing was an exothermal process, which raised the temperature of specimens very quickly within a short period of time. Traditional steam curing of concrete blocks took 18–24 h, CO_2 curing could be completed with 4–8 h including pre-conditioning to achieve strength equivalent to that steam curing, This means that the use of CO_2 curing technology has advantages not only in reducing and/or utilizing greenhouse gas emissions, but also in decreasing the curing time and increasing productivity of plain and non-steel reinforced concrete products.

1. Introduction

Carbon dioxide (CO_2) is the dominant greenhouse gas resulting from human activities. The CO_2 discharged to the atmosphere comes mostly from centralized sources, such as thermal power plants, building and transportation. More than 40% of anthropogenic CO_2 emissions are attributed to the combustion of fossil fuels for the generation of electricity [1]. The Kyoto Protocol on combating climate change was passed in 1997 by over 180 nations with the intent of reducing global carbon emissions to a 1990 baseline. However, emissions have continued to rise, as some countries have been unwilling to take the economic hits that reduced emissions are likely to require [2,3].

In 2009, more than 120 heads of government attended the Copenhagen Climate Change Summit. Both developed and developing nations agreed for the first time to reduce their emissions and to register their national commitments. US announced a target to reduce emissions in the range of 17% below 2005 levels by 2020, 42% below 2005 levels by 2030, and 83% below 2005 levels by 2050. By 2020, China has committed to reduce its CO_2 emissions per unit of GDP by 40–45% from 2005 levels and use non-fossil fuels for about 15% of its energy. China has also committed to increase forest cover by 40 million hectares and forest stock volume by 1.3 billion cubic meters by 2020 (from 2005 levels). Some developed countries also committed to delivering "prompt start" funding to assist developing countries in deploying clean energy technologies, reducing forest-related emissions, and adapting to the impacts of global warming [2,3]. Thus, it is urgent to develop new technologies and products to decrease the CO_2 emission into the atmosphere.

It is well known that CO_2 in the ambient air can penetrate into concrete and react with hydration products of cement such as calcium hydroxides, calcium silicate hydrate, to form calcium carbonate and other products. This process is called carbonation of concrete. For a long time, CO_2 in the atmosphere have been used to cure lime based cements and mortars to achieve required strength. However, the strength development is slow. In the 1970s, several publications reported the use of CO_2 for curing concrete in order to achieve required strength within a very short period of time [4–6]. In the CO_2 curing process, it uses the reactions between CO_2 and minerals in cement clinker. This technique was introduced to the cement-bonded particleboard production to reduce the press time due to the fast setting in a CO_2 rich environment [7–9]. Recently, numerous activities on the sequestration of CO_2 with minerals are occurring in the world to store CO_2 released by the use of fossil fuels in order to prevent its emission to the atmosphere [10–15].

It is a common practice to use steam to cure precast concrete products and concrete masonry blocks after casting. Steam curing

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is an energy extensive process and contributes a significant portion to the production costs. Also, the temperature rise and decrease during the curing process have to be controlled to avoid temperature gradient and cracking of the concrete products. Curing has a strong influence on the properties of hardened concrete such as strength, durability, watertightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicer salts. It is reported that the energy consumption is 2300 kJ for each normal weight standard concrete block and 2500 kJ for each standard lightweight concrete block [16].

In an earlier study, it was found that the CO_2 consumption was very low when pressure-compacted cement or mortars specimens were exposed to CO_2 immediately after molding [14] although most cementitious materials such as Portland cement, granulated blast furnace slag, steel slag, and coal fly ash can react with CO_2 [15]. Many factors affect the reactions between CO_2 and cement clinker minerals [17–19]. This study investigated the effects of pre-conditioning on the CO_2 curing of lightweight concrete block mixtures.

2. Experimentation

2.1. Raw materials

ASTM 150 Type III Portland cement was used in this project. The chemical composition and physical properties of the cement are given in Tables 1 and 2. The expanded shale lightweight aggregate (LWA) used in this project was block mixture with loose unit weight of 945 kg/m^3 (59.0 pcf) and a moisture content of 17.0%. Sieve analysis of the LWA is given in Table 3. Its grading meets both ASTM C330 and ASTM C331 [20,21]. A locally available natural siliceous fine sand with a specific gravity of 2.65 was used. Its sieve analysis is shown in Fig. 1. CO_2 gas with a concentration of 99.5% was used for CO_2 curing of concrete in this study.

2.2. Preparation of specimens and testing programs

2.2.1. Mixture proportion

The concrete mixture proportions used in this project were designed based on the production of lightweight loadbearing concrete block as specified in ASTM C90 [22]. A total of eight mixtures (A1–A4, B1–B4), as summarized in Table 4, were designed and tested during the preliminary laboratory study. The mixture proportions in Table 4 were based on the mass of wet LWA containing 17.0% moisture (saturated surface dry) and sand containing 4.5% respectively. Additional water was

Table 1
Chemical compositions of ASTM Type III Portland cement.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$Na_2O + K_2O$	LOI
(%)	19.39	5.19	2.38	62.86	3.15	4.02	0.61	1.78

Table 2
Physical properties of ASTM Type III Portland cement.

Density (kg/m^3)	3150
Fineness	
Passing 325 mesh (%)	98.9
Specific surface area (blaine) (m^2/kg)	465
Compressive strength (mortar cubes) (MPa)	
1-Day	29.5
3-Day	39.7
7-Day	46.4
28-Day	
Soundness, autoclave expansion (%)	0.198

Table 3
Sieve analysis of lightweight aggregate.

Sieve no.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100
Sieve size (mm)	4.75	2.36	1.18	0.6	0.3	0.150
%, Retained	5.5	32.5	55.9	69.9	78.6	84.4
ASTM C330 specification (%, retained)	0–15	–	20–60	–	65–90	75–95

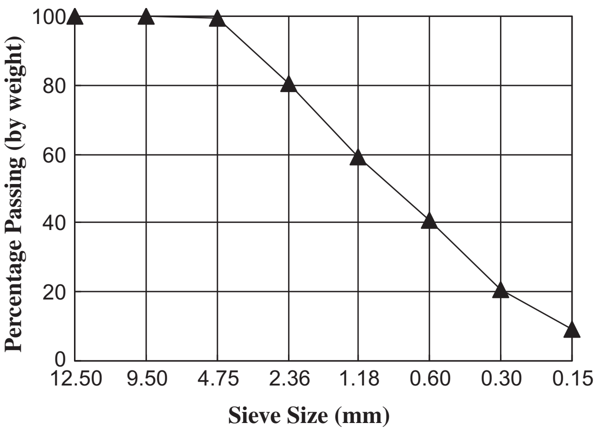

Fig. 1. Sieve analysis of fine aggregate.

Table 4
Mixture proportions of lightweight concrete.

No.	Cement (kg/m^3)	LWA (kg/m^3)	Sand (kg/m^3)	Added water (kg/m^3)	Cement to aggregate ratios (by dry weight)	Effective W/C ratio	V_g/V_s
A1	193	777	815	56	1:7.50	0.47	1.47
A2	205	773	810	53	1:7.00	0.43	1.47
A3	218	763	800	59	1:6.50	0.43	1.47
A4	233	753	789	66	1:6.00	0.43	1.47
B1	217	854	708	63	1:6.50	0.43	1.86
B2	224	849	703	66	1:6.25	0.43	1.86
B3	222	841	697	81	1:6.25	0.50	1.86
B4	246	821	681	94	1:5.50	0.50	1.86

Note: V_g: loose volume of LWA, V_s: loose volume of sand.

Table 5
Pre-conditioning environment.

Pre-conditioning environment	Description
Dry environment	RH = 55 ± 10%, circulated air, $t = 22 \pm 3$ °C
Moist environment	RH > 98%, closed container, $t = 22 \pm 3$ °C

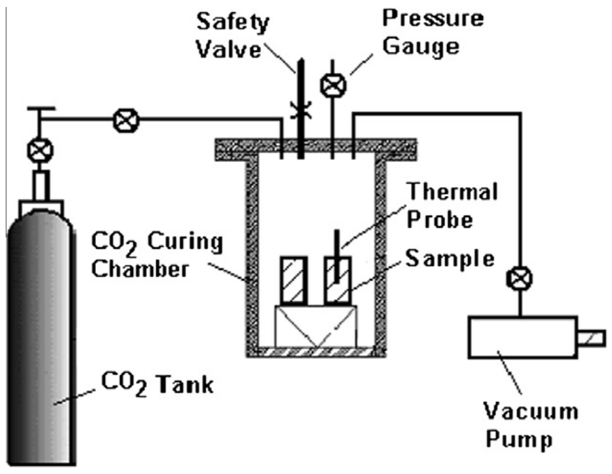

Fig. 2. Illustration of the setup for CO_2 curing of concrete.