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Effect of Different Conditions of Carbon Dioxide Curing in Cement – Based Composites (On Review)

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ABSTRACT

The most concerning issue confronting the planet these days is the ascent in Carbon dioxide (CO₂) levels to record levels. The cement industries are answerable to between 6-8 % of worldwide CO₂ emitting. In construction sectors, researchers tried to contribute in decreasing of CO₂ in atmosphere produced by industry and using that was released in air. Accelerated CO₂ curing is one of the methods used to get benefit from CO₂ in the air. In this paper, CO₂ concentration in addition to pressure, relative humidity and period of curing all had a significant influence upon the features of Cement – Based Composites. Results showed that using CO₂ curing with different and specific properties of fibers (types, quantities, circumstances and lengths) improved the most mechanical properties and enhanced durability such as: strength, stiffness, ductility, toughness, porosity, and absorption.

1. Introduction

Due to the industrial revolution, atmosphere currently contains more CO₂ whenever in any time in at least two million years. At 2020, one ton of cement produce 0.6 tons of CO₂ (Gomez J. 2020). All of this additional CO₂ requires to go somewhere. Until now, land plants and the sea have taken up around 55% of the additional CO₂ which individuals have placed into the climate while around 45% has remained in the air. The expansion in CO₂ motivates an ascent in heat for earth environment. Excess CO₂ within the air makes the air and rain more acidic, putting life in danger (Riebeek, H. 2011).

Recently, there has been a development in the procedure of curing with CO₂ to enhance the performance, mechanical features and durability of composites. The predominant chemical reaction happening with hydrates carbonation includes reacting of carbone dioxide (CO₂) with CH that results out of cement hydrating, which yields calcium carbonate (CaCO₃). The solubility in water for this calcium carbonate seems lesser than of that for CH as well as a decrease within porosity exists in addition to an increase of hardness and impermeability related with the forming process for CaCO₃ (Varjonen, S. 2004). Rapid carbonation reaction might reduce the curing time of cement-based materials by attending of CO₂. This value added utilize CO₂ likewise decrease greenhouse' gas emissions because of utilizing the contaminating CO₂ (Frybort, S., Mauritz, R., Teischinger, A., & Müller, U. 2008) (Zhou, Y., & Kamdem, D. P. 2002) (De Silva, P., Bucea, L., Moorehead, D. R., & Sirivivatnanon, V. 2006). These adjustments within compositions as well as structures improve the durability of cement-based materials at firs ages (Shaikh, F. U. A., & Supit, S. W. M. 2014). In addition, curing with CO₂ will reduce the alkalinity of pores water in cementitious materials (Sharma, D., & Goyal, S. 2018).

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Accelerated curing with CO₂ is diverse from weathering carbonation because it expedite the hydration reactions for un-hydrated phases of C3S and C2S resulting rapid gain of strength. Weathering carbonation exists in concrete after the hydration procedure was predominately finished and outcome the de-calcification of CSH as well as producing gel of silica that is destructive to paste cement (Gilroy, B., Ireland, M., Black, L., Thompson, D., Hogan, R., & Holmes, N. 2020). The utilization of fiber fortifications in cement based materials is growing because of the capacity to cement in a lot attributes to explicit applications and conditions. Extending of using fiber in concrete prompted improves the ductility, toughness and durability (Melenka, G. W., & Carey, J. P. 2015). Fiber utilized in cement-based materials may be of various materials includes steel, glass, carbon, polypropylene (PP), etc.

The first purpose of this paper was to study the utilizing of fiber with accelerating the cure of cement-based materials by CO₂ curing to accelerate hardening and reduce required setting time. Secondly, various relative humidity percentages, curing time, concentrate of CO₂ as well as pressure, which effect on improving of mechanical and sustainable development features for building industry because the consuming of the polluting CO₂.

2. Methodology

The methodology adopted for the review was:

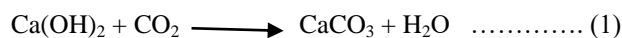
2.1 Accelerated Ageing (Perera, A. S. R., & Al-Tabbaa, A. 2005):

There were various methods of accelerated ageing, the most known ones includes:

1. Elevated Temperatures: hydrating reaction through raising temperature up to 80° C, high temperature affect microstructures.
2. Chemical Accelerators: expedite hydration reactions, but mainly at the beginning.
3. Accelerated Carbonation: expedite carbonation process that is a subordinate reaction of hydration.

2.2 Mechanism of Carbonation

Carbonation is a chemical reaction where CO₂ diffuses into concrete pore system. CO₂ reacts with CH in concrete and forming CaCO₃, (Eq.1). Carbonation makes changes into chemical composition of concrete (Fig. 1). CO₂ mineralizing within the hydrate of cement that occurs whether by natural (weathering) carbonation or by other engineered manner named (accelerated carbonation) (Fig. 2). Weathering carbonation is harmful. CO₂ will react with water of pores and form H₂CO₃ (acid). This acid reacts with CH and produce CaCO₃ results in a small shrinkage. Using CH will reduce pH (alkalinity). In low pH, reinforcement will corrode due to losing passivation. It represents a slow natural method in cementitious material – principally hydrating productions. Accelerated carbonation includes rising the ratio at which carbonation happens (Varjonen, S. 2004). This type of carbonation happened rapidly at early age of cement hydration. Concrete will be stronger, denser and faster develop of strength.



2.3 Factors Influencing Rate of Carbonation (Perera, A. S. R., & Al-Tabbaa, A. 2005):

There are numerous factors influence the rate and congruity of carbonation. The main important factors are: concentration levels of CO₂, CO₂ ratio, permeability/porosity of materials, inner surface area, temperature and relative humidity, and binder system (Fig 3).

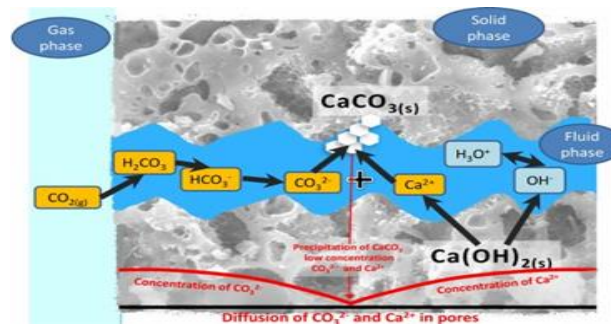


Fig. 1 Mechanism of Carbonation in concrete (Czarnecki, L., & Woyciechowski, P. 2013)

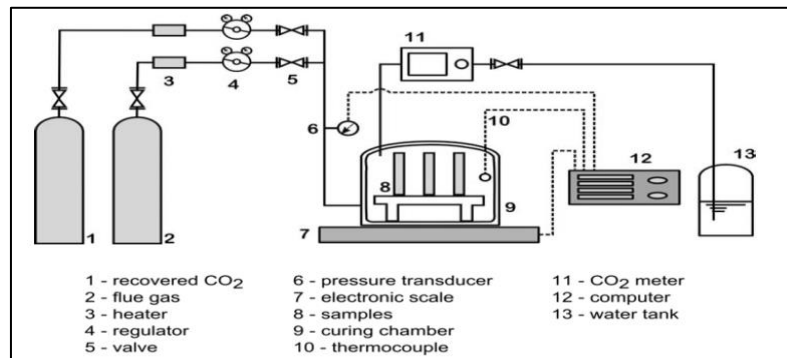


Fig.2 Accelerated CO_2 curing stages

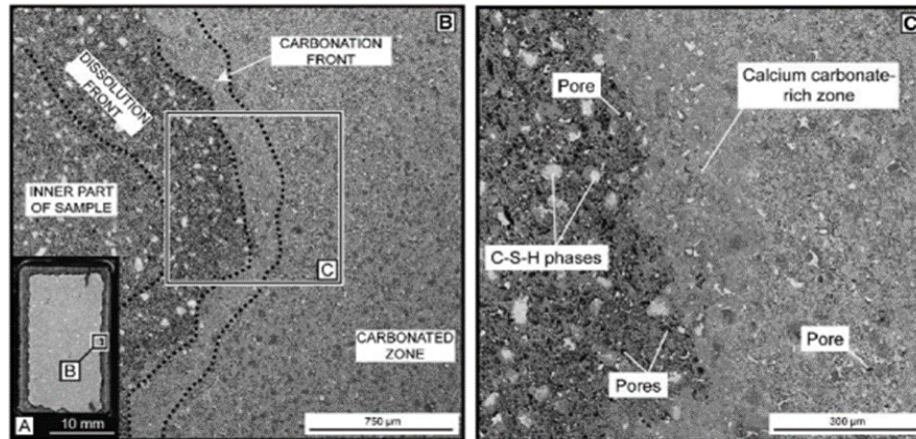


Fig. 3 SEM of carbonated cement paste for 48 hr. at 90°C and 280 bars (Rimmelé, G., Barlet-Gouédard, V., Porcherie, O., Goffé, B., & Brunet, F. 2008).

2.4 Accelerated carbonation of cement-based composites:

Accelerating carbonating is a process to expedite the proportion of carbonation reacting in cement. Different strategies to accelerate carbonation of cement-based materials were practically known through the usage of high concentration of CO_2 at neighbor surrounded cement.

Most generally received engineering method for the mineralizing for CO_2 in cement-based materials is the initial age of CO_2 curing. In initial age, CO_2 curing converts hydrates to steady calcium carbonate (CaCO_3) and gel of silica. Such a method gives a way to CO_2 sequestrating within cement-based materials. Also, such strategy includes utilization of CO_2 gas (bottles) as a supply resource (Fig.2). Another studies (Castellote, M.,

Andrade, C., Turrillas, X., Campo, J., & Cuello, G. J. 2008)(Sanjuán, M. A., Andrade, C., & Cheyrezy, M. 2003) (Chun, Y., Naik, T. R., & Kraus, R. N. 2007)(Al-Kadhimi, T. K. H., Banfill, P. F. G., Millard, S. G., & Bungey, J. H. 1996)(Monkman, S., Logan, C., & Shao, Y. 2006) (Shao, Y., Mirza, M. S., & Wu, X. 2006) showed that the usage concentration of CO₂, which ranges as (0.15% to 100%) for current method of accelerated carbonation.

The fiber/matrix interfacial zone allowed calcium carbonate to sedimentate largely during a carbonation curing. This cause a reduction in capillary and gel porosity around the fibers. A difference in Calcium/Silica (Ca/Si) proportion near to the interface was revealed through EDS (Energy Dispersive Spectroscopy) (Fig. 4)(Santos, S. F., Schmidt, R., Almeida, A. E. F. S., Tonoli, G. H. D., & Savastano, H. 2015) .

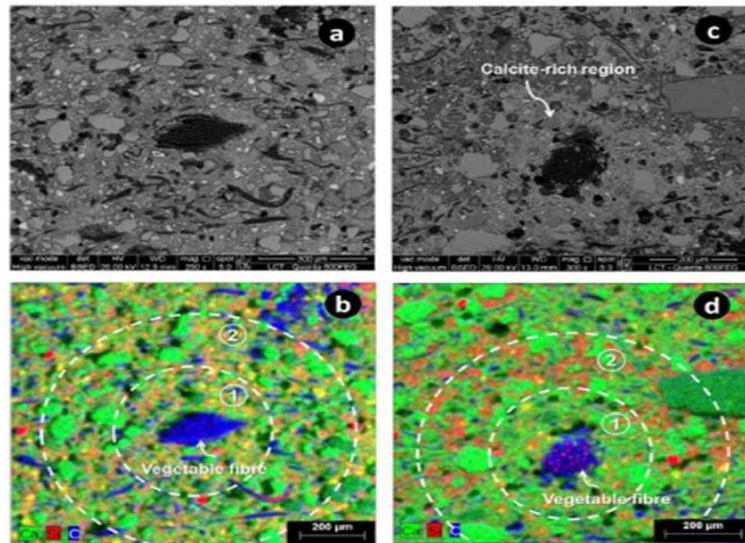


Fig. 4 SEM/BSE and EDS mapping of fiber composites: (a) and (b) no-carbonated;(c) and (d) after carbonation. Ratio Ca/Si in zones 1 and 2 near of fibers was calculated by EDS

3. Results of the Experimental Work:

Authors	Conditions of CO ₂ Curing	Conclusions
(Al-Kadhimi, T. K. H., Banfill, P. F. G., Millard, S. G., & Bungey, J. H. 1996)	<ul style="list-style-type: none"> • 60% relative humidity (RH) or less. • subjected to CO₂ gases by 100 % , (1.5 MPa) • cementitious materials 300 kg/m³ and with water/cement ratio = 0.63 	<ul style="list-style-type: none"> • They concluded that such samples to be completely got carbonation within period of two weeks by accepting such technique of accelerated curing • Also observed that using high water-to-cement ratio was preferable to simplify the CO₂ diffusing as the samples got subjected to 100% CO₂ environment.
(Sanjuán, M. A., Andrade, C., & Cheyrezy, M. 2003)	<ul style="list-style-type: none"> • Lab climate of 50 ± 5% RH and 22 ± 2 °C. • Concentration of CO₂ to 100%. 	<ul style="list-style-type: none"> • Observed as many as 40 times higher carbonating rate to accelerated process than the normal carbonation a remarkable variation in microstructure of carbonated concrete by high CO₂ concentrating with normally carbonated concrete. • It was deduced that CO₂ concentration of 5% reveal less impact to microstructure comparing with high CO₂ concentration.

(Chun, Y., Naik, T. R., & Kraus, R. N. 2007)	<ul style="list-style-type: none"> Concrete mixture with a fly ash Class (C) with cementitious materials (0, 18, and 35%). Methods of curing: <ul style="list-style-type: none"> Moisture curing with 100% RH + 0.15% of CO₂. Dry curing with 50% RH + 0.15% of CO₂. Cured in chamber of CO₂ and 50% RH + 5% of CO₂. 	<ul style="list-style-type: none"> Found high rate of carbonation within carbon CO₂ 5% concentration. Observed mechanical characteristics of concrete samples maintained in the chamber with the same that for samples cured with moisture. The abrasion resistance of carbonated samples was low compared with moisture cured.
(Castellote, M., Andrade, C., Turrillas, X., Campo, J., & Cuello, G. J. 2008)	<ul style="list-style-type: none"> Three kinds of binders were utilized for producing pastes. The first binder was CEM I 42.5 R sulphate-resistant, with lime (5%) adding. The other binder is a mixture utilizing similar cement replaced of a 35% fly ash. The last mixture was that replaced of a 10% by microsilica. w/c ratio of 0.5 Using water for mixing in first mix and deuterated water for the second. temperature (22 °C) with a RH, higher than 95% carbonation with 100% CO₂ concentration+ RH of about a 65% and 22 °C 	<ul style="list-style-type: none"> Found very similar microstructure for pastes carbonated. When a complete carbonating done, each specimen became denser. The decreasing ratio for any stage was dissimilar to various mixtures. While in similar mixtures, the other phases' rate are various, in same time, maintain the proportional among phases in various samples. Ettringite reacts faster, after that, the crystalline volume. The consumption of Portlandite, are slowest persistent process.
(Soroushian, P., Won, J. P., & Hassan, M. 2013)	<ul style="list-style-type: none"> Initial curing, 30 minutes at 50°C in oven. Pressed boards. Concentration of CO₂ = 25 %. 	<ul style="list-style-type: none"> Matrix of cementitious composite modified by CO₂ curing. The testing outcomes showed that continued cycles of wet-dry and freezing-thawing which leads to enhance stiffness and decrease toughness. The consequences for modulus of rupture were mixed.
(Soroushian Prof., P., Won Prof., J. P., & Hassan, M. 2013)	<ul style="list-style-type: none"> Pressed and unpressed boards. Various oven's temperature, periods, CO₂ chamber and autoclave periods. 	<ul style="list-style-type: none"> Increasing modulus of rupture and toughness were gained through increasing oven, CO₂ exposure and autoclave period. Reducing oven time increases stiffness but increases exposure duration in chamber and autoclave produced higher stiffness.
(Hamad, A. 2014)	<ul style="list-style-type: none"> Initial curing, 30 minutes at 50°C in oven. Concentration of CO₂ = 100 % and for 2-3 days. 	<ul style="list-style-type: none"> Strength value of samples were increased in age's range of 7 to 28 days.
(El-Hassan, H., & Shao, Y. 2014).	<ul style="list-style-type: none"> Initial curing: 4 - 18 hrs. with RH of 50% at 25°C. 4 hr. carbonation curing to allow concrete for uptaking (22-24%) CO₂ in addition to primary curing and 8.5% without primary curing, while extended 4-day carbonation had an uptake of 35%. 	<ul style="list-style-type: none"> Reduce carbonation period to 2-4 hrs. and using initial curing ranged from 0-18 hrs. to cost purpose. Primary curing effect on carbonation degree was estimated to raise maximum potential carbon uptake in Chamber Unit.
(Hassan, M., & Salih, W. 2016)	<ul style="list-style-type: none"> Percentages (2, 6, and 10%) of palm fiber was utilized by weight of cement 	<ul style="list-style-type: none"> For compressive strength, CO₂ curing, was best method curing. Autoclave curing gives best enhancement

	<ul style="list-style-type: none"> • C:S= 1:2.75 • Aging cured with carbonation or autoclave at age 24 hr. then stored into the sealed bags until age of 28 day • Carbonation includes initial curing, 30 minutes at 50°C in oven + Concentration of CO₂ = 50 % and for 2 hr. • autoclave includes pressure reaches 2 MPa for 2 hr. 	<ul style="list-style-type: none"> • for modulus of rupture. • Methods of accelerated curing effected the performance of direct tension have fluctuation • For plain mortar samples, utilization of CO₂ curing develop compressive and direct tension significantly than autoclaved specimen
(Abed, Z. M., Hassan, M. S., & Faisal, R. H. 2018)	<ul style="list-style-type: none"> • Polypropylene fibers (0, 0.3, 0.9, and 1.5%) • cement: silica fume: Sand with proportion of (1: 0.75: 1.3) and w/c ratio= 0.5 • Concentration of CO₂ = 100 % and for 2 hrs. 	<ul style="list-style-type: none"> • significant development of modulus of rupture and direct tension for samples especially at (1.5% polypropylene) about (+ 28%) and (+ 117%) respectively. • Decrease in compressive strength.
(Abed, Z. M. 2020).	<ul style="list-style-type: none"> • replacement of sand using rockwool fibers (0, 2, 4 and 6%) and lengths (5 and 10 mm) • Two curing methods: firstly, CO₂ curing at age 24 hr. then stored into the sealed bags until age of 28 day. Secondly, contentious water curing 	<ul style="list-style-type: none"> • Development in compressive strength, modulus of rupture, and absorption were about 43% and 81%, 18% and 37%, and -35% and -40% for water and CO₂ curing, respectively

4. Conclusions:

Depend on the previous references, it can be concluded that:

- Numerous benefits for the initial age carbonating curing to concrete and another cementitious material.
- Compared to moist-cured concrete, the concrete cured in the CO₂ chamber (with 0.15% CO₂ concentration) exhibited an approximate similar strength and low abrasion resistance.
- Early age carbonation expedite strength gaining, prompting shorten period for producing precast members.
- With Initial curing, 30 minutes at 50°C in oven and concentration of CO₂ = 25 %, the CO₂ curing improved the matrix of cementitious composites, raised stiffness and decrease toughness values. But when use concentration of CO₂ = 100 % and for 2-3 days, all mechanical properties of cementitious samples were increased due to aging ranged (7-28 days).
- Also, the advantages of utilizing CO₂ curing, which has a high impact on sustainability in the construction industry due to the disposal of CO₂ and for cost purpose.
- The Utilization of CO₂ concentrating, which ranges from (0.15- 100%) increases the mechanical strength of cement-based materials.
- Fundamentally the same as microstructures for pastes carbonated within a climate up to 3% CO₂ concentrating with nature carbonation.
- An essentially different microstructures of paste cured with high CO₂ concentration ranged (10-100%) than the natural carbonation process.
- A high water/cement ratio is preferable to ease the dissemination of carbon dioxide through exposing samples to 100% carbon dioxide.
- Carbonation curing was the most effective curing and better than autoclave curing for compressive strength. Otherwise, autoclave curing exhibits better results in flexure.
- Using carbonation for cement based composite with different fibers improve most of properties according to the types, percentages and properties of replaced fiber.

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