

# Improving Carbon Sequestration in Concrete: A Literature Review

Adedokun D. A., Ndambuki J. M., and Salim R. W.

**Abstract**—Due to urbanization, trees and plants which covered a great land mass of the earth and are an excellent carbon dioxide (CO<sub>2</sub>) absorber through photosynthesis are being replaced by several concrete based structures. It is therefore important to have these cement based structures absorb the large volume of carbon dioxide which the trees would have removed from the atmosphere during their useful lifespan. Hence the need for these cement based structures to be designed to serve other useful purposes in addition to shelter. This paper reviews the properties of Sodium carbonate and sugar as admixtures in concrete with respect to improving carbon sequestration in concrete.

**Keywords**—Carbon sequestration, Sodium carbonate, Sugar, concrete, Carbon dioxide.

## I. INTRODUCTION

THE causes of recent global warming are still being subjected to research. However, there is a scientific consensus which identifies human activities as the main influence of increased levels of green house gases which have been verified over a period of 50 years [1]. The United Nations Framework Convention on Climate Change [2] defines carbon sequestration as the process of the removal of CO<sub>2</sub> from the atmosphere and depositing it in a reservoir. In a bid to reduce global warming, artificially capturing and storing carbons as well as enhancing natural sequestration processes using sinks are being explored. CO<sub>2</sub> sinks are ecosystems (the main ones being soil, oceans and forests) that store carbon dioxide in water, sediment, wood, roots, leaves and the soil [3]. The two basic types of CO<sub>2</sub> sinks are the natural and artificial sinks.

## II. NATURAL SINKS

### A. Forest

The forest is made up of trees and other plants which undergo photosynthesis. Photosynthesis involves the absorption of carbon dioxide from the atmospheres by plants and the conversion of the CO<sub>2</sub> to sugar, starch and cellulose with release of oxygen into the atmosphere [4].

Young forest, which comprises of growing trees, absorbs CO<sub>2</sub> for photosynthesis and acts as a sink, while matured forests, comprising of various aged trees as well as dead and

decaying matter is likely to be at a carbon neutral state, as they will emit and absorb almost equal amounts of CO<sub>2</sub> [3].

### B. Ocean

The oceans are known to be the largest active sink on earth, with approximately one – quarter of man-made emissions estimated to be entering it at present [3]. The role of ocean as a sink for CO<sub>2</sub> is influenced by two processes which are: the solubility pump and the biological pump [5]. The Solubility pump process is based on the difference in the solubility of CO<sub>2</sub> in seawater and thermo line circulation. On the other hand, the biological pump is the cumulative biological processes which transports carbon (in organic and inorganic forms) from the surface euphotic zone to the interior of ocean [5].

However, a sustained high concentration of CO<sub>2</sub> is likely to cause mortality of ocean organisms and thus negative consequences on the ecosystem [6]. Although the buffering capacity of seawater is keeping the pH nearly constant at present, eventually pH will drop resulting in the disruption of life in the sea which may turn it into a CO<sub>2</sub> source rather than a sink [6].

## III. ARTIFICIAL SINKS

### A. Ocean

A proposed form of carbon sequestration in the ocean is direct injection. This process involves CO<sub>2</sub> being pumped directly into depths of the ocean, to form “lakes” of liquid CO<sub>2</sub> at the ocean bed [6]. The reaction between the infused carbon dioxide and water yields carbonic acid (H<sub>2</sub>CO<sub>3</sub>), which could potentially be dangerous to the ecosystem leading to the death of plants and living organisms in the ocean. Thus, this form of sequestration may have potentially dangerous environmental consequences [6].

### B. Geological Sequestration

Geological sequestration is defined as “the process of injecting carbon dioxide (CO<sub>2</sub>) captured from an industrial (e.g., steel and cement production) or energy-related source (e.g., a power plant or natural gas processing facility), into deep subsurface rock formations for long-term storage” [7]. Due to the geology of oil fields, there is a difficulty of the upward movement of underground oil and it is hoped that as CO<sub>2</sub> is injected into this field on a long term basis, more oil will be recovered [8].

## IV. CONCRETE CARBONATION

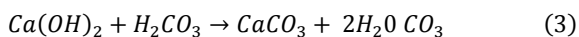
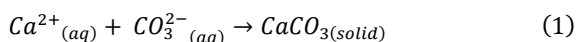
Carbonation is a chemical process where atmospheric CO<sub>2</sub> reacts with calcium hydroxide (CaOH)<sub>2</sub> in the concrete to form

D. A. Adedokun, is a postgraduate student at the Civil Engineering Department, Tshwane University of Technology, Pretoria, 0001 (Phone: +27-73-820-5877e-mail: AdedokunDA@tut.ac.za)

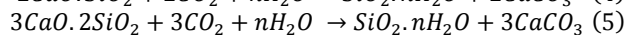
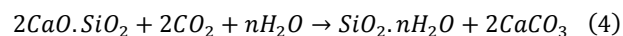
J. M. Ndambuki is with the Civil Engineering Department, Tshwane University of Technology, Pretoria, 0001. (Phone: +27-12-382-5225; fax: +27-12-382-5226; e-mail: NdambukiJM@tut.ac.za).

R. W. Salim is with the Civil Engineering Department, Tshwane University of Technology, Pretoria, 0001 (Phone: +27-73-778-6390,e-mail: SalimRW@tut.ac.za).

calcium carbonate ( $\text{CaCO}_3$ ) [9]. The carbonation process is a relatively slow process as atmospheric  $\text{CO}_2$  must diffuse into the concrete and dissolve in the concrete pore fluid. It is a process occurring from the surface of a concrete structure and inwards, and is dependent on the diffusion rate of  $\text{CO}_2$  into the concrete [9]. Research carried out in South Africa [10] on concrete bridges casted between 11 to 76 years indicated that at 76 years of casting, carbonation in concrete is still evident except that carbonation rate was lower compared to newer structures. Surfaces in direct contact with carbon dioxide and water carbonate to form carbonate ions which reacts with the calcium compounds in concrete (primarily  $(\text{OH})_2$ ) and form calcium carbonate according to reaction equations 1 to 3 [9].



Un-hydrated dicalcium silicate ( $\text{C}_2\text{S}$ ) and tricalcium silicate ( $\text{C}_3\text{S}$ ), which are the main hydration constituents in concrete are also prone to carbonation though their carbonation does not directly affect the alkalinity of the concrete [11]. These are represented by reaction equations 4 to 5.



where  $n$  represents an arbitrary positive number of moles of water that is conserved through the reactions

The rate and degree of carbonation is governed mainly, by the environmental influences on the concrete and the compositional effects of the concrete [12]. These environmental influences which includes: the size and geometry of the porous structure, the degree of water saturation in the pore system, the type of cement/binder, the chemistry of the pore solution, the temperature, and the concentration of  $\text{CO}_2$  in the atmosphere.

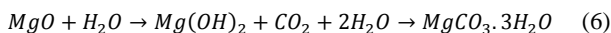
Carbonation of hydrated Portland cement yields an improvement of its compressive strength and hardness [13] in addition to reducing its permeability and shrinkages [14]. Moreover, there is also volume stability which prevents further volume destabilization with further moisture changes.

## V. IMPROVING CARBONATION IN CONCRETE

### A. Eco-cement

Eco-Cement is a type of cement which incorporates reactive magnesia (sometimes called caustic calcined magnesia or magnesium oxide,  $(\text{MgO})$ ) and hydraulic cement such as Portland cement, and optionally pozzolans and industrial by-products, to reduce the environmental impact relative to conventional cement [15]. Eco-cement absorbs carbon dioxide while setting. The carbonation of magnesia is illustrated by equation 6 which shows that magnesia first hydrates to form

brucite which is unstable and therefore carbonate to form nesquehonite.

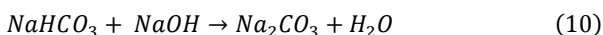
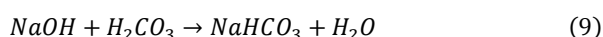
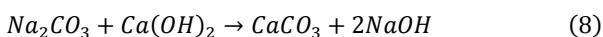
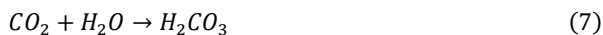


Eco-cement is unique as its production requires lesser energy as magnesia needs to be heated to a temperature of about 600-750°C before a reactive magnesium oxide can be gotten compared to the energy consumption of calcium carbonate in the kiln which is about 1450 °C [16]. Eco-cement utilizes wastes in its production and it shows a potential for  $\text{CO}_2$  sequestration on a large scale.

### B. Sodium Carbonate in Concrete

Sodium Carbonate ( $\text{Na}_2\text{CO}_3$ ) is hitherto used in concrete as an accelerating admixture as seen in the manufacture of shotcrete. Shotcrete is a mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto backup surface [17].  $\text{Na}_2\text{CO}_3$  is also used in concrete as a cathodic corrosion inhibiting admixtures due to its high alkalinity. It thus increases the PH of the near surface of the reinforcement steel, thus protecting the passivity layer around the steel reinforcement in concrete [18].  $\text{Na}_2\text{CO}_3$  possess a good chemical property that can favor the sequestration of  $\text{CO}_2$ . When concrete absorbs  $\text{CO}_2$ , it reacts with water present in the concrete pores to form carbonic acid, as shown in equation 7.

Equation 8 indicates that washing soda can react with calcium hydroxide in hydrated concrete to form sodium hydroxide and a stable calcium carbonate. Sodium hydroxide can in turn react with the carbonic acid formed by equation 7 to produce more sodium carbonate as shown in equations 9 and 10. The availability of excess water produced could also help the hydration process in concrete.



There exist two distinct stages in cement pastes formation which have  $\text{Na}_2\text{CO}_3$  incorporated into them. The first stage involves the formation of gel- like hydrated products which yields the development of microcrystalline  $\text{Ca}(\text{OH})_2$  particle development.  $\text{Ca}(\text{OH})_2$  has a high affinity for  $\text{CO}_2$  which is present in the environment. This leads to the formation of vaterite and calcite. This process is intensively higher within the first 24 hours of the hydration, after which it tends to progress at a slower rate up to the 28th day of curing [19]. The second stage of the hydration process involves the intense carbonation of the cement paste, which is initiated by the presence of more  $\text{CO}_3^{2-}$  ions in cement pastes with  $\text{Na}_2\text{CO}_3$ , after the first 24 hours of hydration when compared to the control cement paste.

### C. Sugar in Concrete

Sugar with chemical formula  $C_{12}H_{22}O_{11}$  has its application in the construction industry where it serves as a retarding admixture. At an appropriate dosage of 0 to 1% [20], sugar has the tendency to increase the 28 days compressive strength of concrete.

Sugar in concrete works by slowing down the reaction of Tricalcium Aluminate ( $C_3A$ ) and Tricalcium Silicate ( $C_3S$ ); the fastest hydrating cement reactant groups [21], which initiates the hydration process in the early stages. After a while, the hydration process continues at an accelerated rate due to the initially slower reaction group Dicalcium Silicate ( $C_2S$ ). The heat of reaction allows the hydration to continue at a normal rate until completion. The retardation effect of sugar are usually manifested within the first 24 to 72 hours [22] and is eventually incorporated into the hydrated cement paste with its action having no detrimental consequence to the composition or identity of the hydrated concrete.

### VI. CONCLUSION

With the review of the chemistry of Sodium carbonate in concrete and the effect of sugar on its setting time, the following conclusions can be made:

- Sodium carbonate in concrete shows a potential of boosting carbon sequestration from the environment.
- Sugar indicates a potential of keeping hydration of concrete at a normal rate even in the presence of sodium carbonate.

### ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Tshwane University of Technology for financing this research.

### REFERENCES

- [1] IPCC. 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881pp. Intergovernmental Cambridge University Press, (ISBN) 0-521-80767-0 (Pb: 0-521-01495-6).
- [2] United Nations Framework Convention On Climate Change. n.d. *Glossary of climate change acronym* [Online]. Available from: <http://unfccc.int/essential/background/glossary/items/3666.php#C>. [Accessed 17 August, 2012].
- [3] Earthwatch Institute (Europe), n.d. *Climate Change: mitigation – carbon capture and storage*. Earthwatch, Institute (Europe) 267 Banbury Road, Oxford OX2 7HT United Kingdom.
- [4] Smith A.L. 1997. *Oxford Dictionary of Biochemistry and Molecular Biology*. Oxford [Oxford shire]: Oxford University Press. ISBN 0-19-854768-4.
- [5] Raven, J. A. And Falkowski, P. G. 1999. *Oceanic sinks for atmospheric CO<sub>2</sub>*. Plant Cell and Environment, Blackwell science ltd.22 (6). Pp.741-755.
- [6] IPCC, 2005: *IPCC Special Report on Carbon Dioxide Capture and Storage*. Prepared by: Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., Davidson, O., de Coninck, H. C., Loos, M. and Meyer, L. A. (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- [7] United States Environmental Protection Agency (USEPA). 2012. *Geologic Sequestration of Carbon Dioxide* [Online]. Available from: [http://water.epa.gov/type/groundwater/uic/wells\\_sequestration.cfm](http://water.epa.gov/type/groundwater/uic/wells_sequestration.cfm). [Accessed 17 August, 2012].
- [8] Hovorka, S. 2009. *Risks and Benefits of Geologic Sequestration of Carbon Dioxide - How Do the Pieces Fit?* [pdf]. Available from: [http://www.searchanddiscovery.com/documents/2009/80058hovorka/ndx\\_hovorka.pdf](http://www.searchanddiscovery.com/documents/2009/80058hovorka/ndx_hovorka.pdf). [Accessed on 16/11/2012].
- [9] Lagerblad, B. 2005. *Carbon Dioxide Uptake during Concrete Life Cycle, state of the art*. Swedish Cement and Concrete Research Institute -CBI, www.cbi.se, ISBN 91-976070-0-2, 2005. pp. I – 47.
- [10] Alexander, M.G., Mackechnie, J.R., Yam, W.2007. Carbonation of concrete bridge structures in three South African localities. ScienceDirect 29(2007). Pp.750-759.
- [11] Peter, M., Muntean, A., Meier, S., Bohm, M. *Competition of Several Carbonation Reactions In Concrete: A Parametric Study*. Elsevier. Cement and Concrete Research. 38(2008). pp.1385-1389.
- [12] Gajda, J. And Miller, F. M. 2000. *Concrete as a Sink for Atmospheric Carbon Dioxide: A Literature Review and Estimation of CO<sub>2</sub> Absorption by Portland Cement Concrete*. PCA R&D Serial No. 2255. Portland cement Association, Skokie. pp.1-28.
- [13] Shao, Y., Monkman, S., 2006. Carbonated Cementitious Materials and Their Role in CO<sub>2</sub> Sequestration. In: M.S, Konsta-Gdoutos, ed. 2006. *Measuring, Monitoring and Modelling Concrete Properties*. Netherlands: Springer. pp. 353-359.
- [14] Verbeck, J., 1958. Carbonation of hydrated Portland cement. Cement and concrete special technical publication no. 205. American Society for Testing Materials. pp. 17-36.
- [15] Harrison, W and John, A. 2008. *TecEco Eco-Cement Masonry Product Update – Carbonation =Sequestration*. TecEco Pty. Ltd., Hobart, Tasmania, Australia. pp.1-9.
- [16] Pearce, F., 2002. *Green Foundations*. New Scientists Magazine. 175(2351). pp. 9-40
- [17] Neville, A.M. and Brooks, J.J., 2010. *Concrete Technology*. 2<sup>nd</sup> ed. Malaysia: Pearson education limited.
- [18] Mindess, S. Young, J.F. And Darwin, D. 2003. *Concrete*. 2<sup>nd</sup> ed. Prentice Hall, Upper Saddle River, NJ 07458. ISBN 0-13-064632-6.
- [19] Janotka, I., 2000. *Hydration of the Cement Paste with Na<sub>2</sub>CO<sub>3</sub> Addition*. Institute of Construction and Architecture, Slovak Academy of Sciences, 45 (1). pp.16-23.
- [20] Abalaka.A.E. 2011. *Effects of Sugar on Physical Properties of Ordinary Portland cement Paste and Concrete*. AU J.T. 14(3): 225-228.
- [21] Collepardi, M. 1984. *Water Reducer/Retarders*. In: Concrete Admixtures Handbook: Properties, Science, and Technology, Ramachandran, V.S., Ed. Noyes Publications, Park Ridge, NJ. pp. 116–210.
- [22] Whitney D.P., 2008. *Chemical admixtures*. In: Nawy E.G. (ed.) *Concrete Construction Engineering Handbook*. Published by: Taylor & Francis CRC Press 2008. pp.1-20.