Rapid complete carbonation in porous cement building products

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Abstract:

Porous cement blocks with an embedded air tube were submerged in water with high calcium content, air was continuously pumped through the hose. Within 7 days carbonation was complete, recapturing all CO2 produced during manufacture in the decarbonation of limestone. The resulting block was 150% higher compressive strength. This method is used to prototype a building product in which cast cement structures sequester CO2 from the air.

Introduction:

Carbon dioxide levels have increased over the last 150 years with the UN Intergovernmental Panel on Climate Change report stating the need for large scale carbon sequestration[1]. One method of sequestering carbon from the atmosphere is mineral carbonation or mineralization[2]. Mineralization is the process in which CO2 in air or dissolved in water (as carbonic acid) reacts with minerals such as Calcium to produce CaCO3 (Calcium carbonate) or other carbonates. Results have shown that injecting CO2 dissolved into water in rock formations with high mineral content can sequester the CO2 as rock rapidly.[3]

The favorable economics of mineralization are dependent on a market for the sequestration of CO2 and a paid price per sequestered ton which is more than the cost of the process per ton. One method for improving the economic balance is to produce an end product that has additional value such as building materials. Carbonates are used extensively in building products, examples being wall plaster, concrete, aggregates, roof tiles and more. Carbonates have a superior characteristic to other build supply sequestration, like wood[4], in that the CO2 is

[1] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

[2] Mazzotti, M. & Abanades, Juan & Allam, Rodney & Lackner, K.S. & Meunier, Francis & Rubin, E. & Sanchez, J.C. & Yogo, K. & Zevenhoven, R.. (2005). Mineral carbonation and industrial uses of carbon dioxide. IPCC Special Report on Carbon Dioxide Capture and Storage. 319-338.

[3] Matter, Juerg M.; Stute, Martin; Snæbjörnsdottir, Sandra O.; Oelkers, Eric H.; Gislason, Sigurdur R.; Aradottir, Edda S.; Sigfusson, Bergur; Gunnarsson, Ingvi; Sigurdardottir, Holmfridur; Gunlaugsson, Einar; Axelsson, Gudni; Alfredsson, Helgi A.; Wolff-Boenisch, Domenik; Mesfin, Kiflom; Fernandez de la Reguera Taya, Diana; Hall, Jennifer; Dideriksen, Knud; Broecker, Wallace S. (June 10, 2016). "Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions". *Science*. **352** (6291): 1312–1314. Bibcode:2016Sci...352.1312M. doi:10.1126/science.aad8132. PMID 27284192.

[4] Ingerson, Ann. (2011). Carbon storage potential of harvested wood: Summary and policy implications. Mitigation and Adaptation Strategies for Global Change. 16. 307-323. 10.1007/s11027-010-9267-5.

sequestered in a stable state for geological time scales. There are multiple companies that already sequester CO2 in carbonate building materials such as Blue Planet Systems[5] and Carbon Cure[6]. Another ancient example is Eifel Marble which is a kind of limescale of sequestered CO2 which built up in roman aquaducts and was then used as a synthetic stone building material.

Column of Eifel Marble

Over 10 billion tons of concrete made per year in world[7] comprising an estimated 4 billion tons of cement. Current human generation is estimated at 51 billion tons of CO2[8]. If carbon could be sequestered in cement with a net positive sequestration (considering CO2 production in all inputs including energy) the scale of the cement built industry could significantly reduce human CO2 production.

This paper describes a process that could sequesters net positive CO2 including energy inputs, is more economical than current methods, and produces a superior product.

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[5]Blueplanetsystems.com. 2022. [online] Available at: <https://www.blueplanetsystems.com/> [Accessed 31 January 2022].

[6] https://www.carboncure.com/. 2022. [online] Available at: <https://www.carboncure.com/> [Accessed 31 January 2022].

[7] Meyer, Christian. (2004). Concrete Materials and Sustainable Development in the USA. Structural Engineering International. 14. 203-207. 10.2749/101686604777963757.

[8] Hannah Ritchie and Max Roser (2020) - "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions' [Online Resource]

Sample Preparation

To prepare a sample, a 94lb bag of Holcim Type II Portland Cement was mixed with 6 gallons of municipal water. A foaming agent[9] was mixed with water to create a dense foam at approximately 60 grams per quart. Mix the cement and foam with a 1:7 ratio and pour the mix into a rectangular form with a depth of 5 cm. The mix was allowed to cure for 1 year. However, 30 days should all be required. A 5 cm hole saw was used to cut a cylinder out of the rectangle.

The sample was 34.5 grams.

Hot glue was used to block one end of the center hole in the sample and a 1 cm diameter and 30 cm airline was glued into the other whole. With the glue and tube the total weight was 40 grams.

The airline was connected to a Tetra Whisper 10 aquarium air pump[10] with .5 L/min of air flow at 1.5 watts power consumption

The sample was inserted into a 500 ml plastic tank. The sample was wrapped around a heavy steel weight with a copper wire and placed on the bottom of the tank. Approximately 300 ml of distilled water was added to the tank. Over the next 7 days the pump was run continuously and 328 grams of CaCl were periodically added to the container. The CaCl readily dissolved into the water. Throughout the test period a white power began to precipitate in the bottom of the container. This white precipitate may be CaCO3. After 7 days submerged the sample was removed and allowed to sit for 2 days in ambient air. The sample was then baked for 30 mins at 120 celsius and then weighed, the sample alone weighed 62 grams. The sample had gone from 34.5 grams to 62 grams, sequestering 27.5 grams of CO2.

[9] https://www.drexchem.com/products/f-m-160/
[10] https://www.tetra-fish.com/products/aeration/whisper-aquarium-air-pump.aspx

Fig 1: Untreated sample tested with phenolphthalein shows ongoing carbonation

Fig 2: Treated sample tested with phenolphthalein shows complete carbonation

An untreated sample and the treated sample were cut in half and phenolphthalein was brushed onto the exposed samples. In the untreated sample carbonation is still ongoing as indicated by the bright purple. In the treated sample, all carbonation is complete as indicated by the lack of color.

The phenolphthalein results suggest that the increase in weight is due to the sample sequestering CO2 first accelerating the carbonation and then by sequestering additional CO2.

Compressive Strength Testing

Multiple samples were prepared as above from the same rectangular block. The samples were loaded into a compression testing device in which a load was placed across two wooden blocks on either end of the sample. The breaking point was the load on the sample when the sample broke.

Three plain samples with no additional steps after sawing were tested with an average break strength of 650,433 units. The sample which had sequestered CO2 was tested with a break strength of 1,001,020 units. A calibration of the device sets 2308 units per kg. The plain samples broke at 281 kgs and the CO2 sequestered blocks at 433 kgs.

This is a compressive strength increase of 150%.

Pictures of the Broken Samples

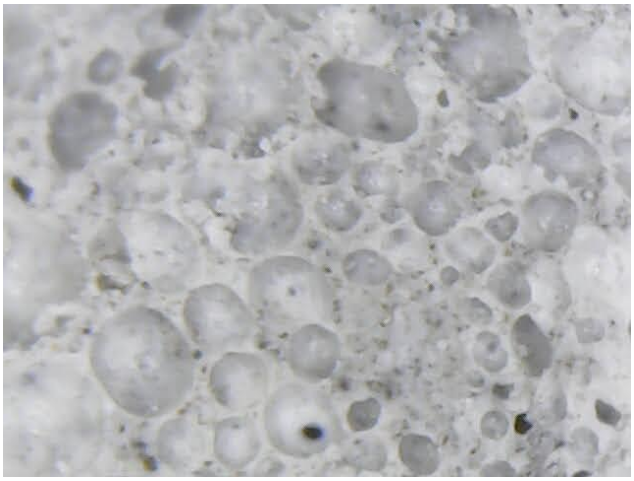

Fig 1: Inside Plain Sample

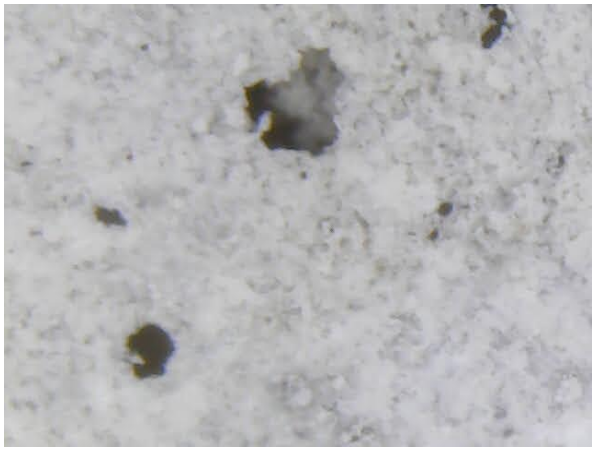

Fig 2 - Surface of Plain Sample

Fig 3: CO2 Sequestered Sample Cross Section

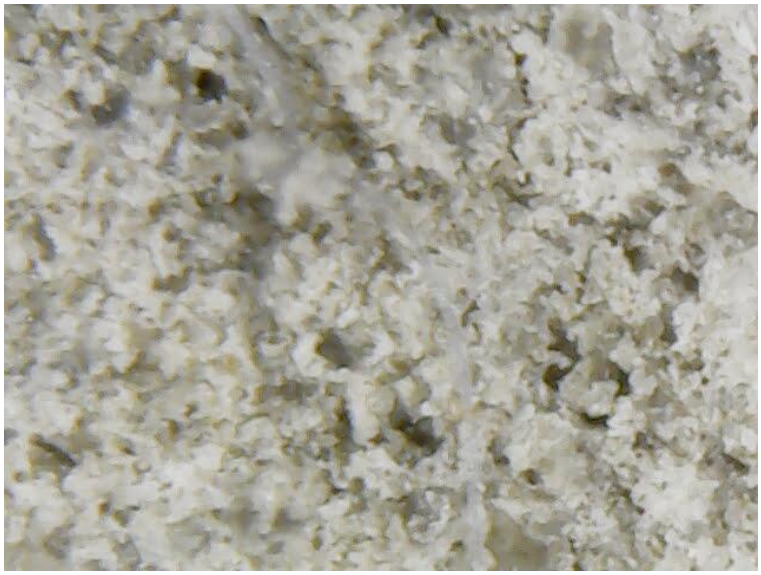

Fig 4: Surface of CO2 Sequestered Sample

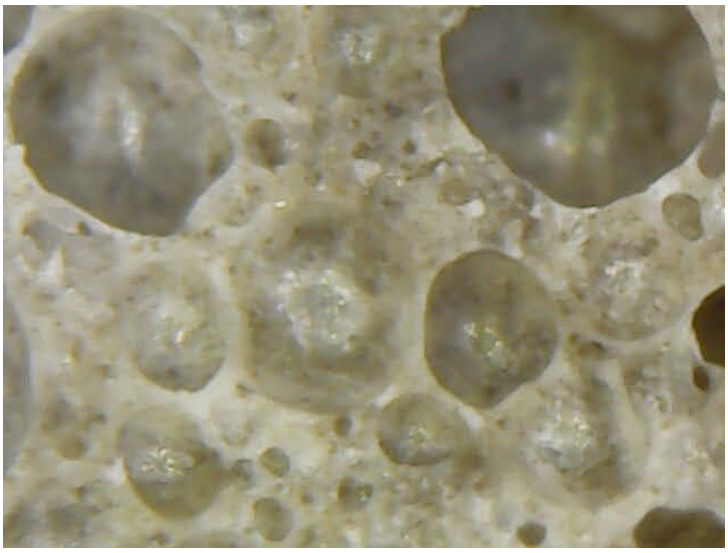

Fig 5: Inside CO2 Sequestered Sample

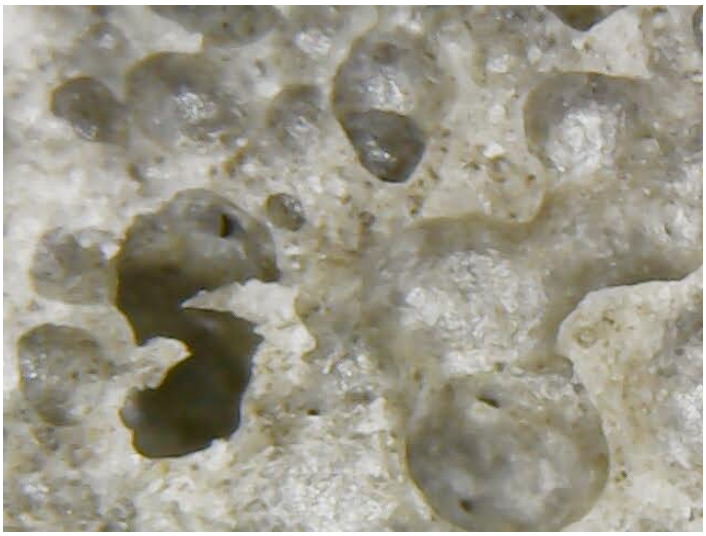

Fig 6: Inside CO2 Sequestered Sample

The CO2 Sequestered sample is a darker and shinier color. In Fig 3, with the cross section there is a visible layer of darker material which surrounds the lighter core.

Sealed container test

A larger sample was cut from the rectangle sample which weighed 244 grams. A tube was inserted, without glue, into a hole in the side.

The sample with the air pump and a CO2 measuring device[11] were inserted into a sealed container with a size of 3.9 liters. 60 grams of CaCl and 500 ml of distilled water were added to the container.

Time Under Test (mins)	Parts Per Million CO2
0	634
30	246
60	200
120	191
720	177

The sample was removed and sat for 24 hours drying and was weighed at 295 grams. Then it was placed into a 120C oven for 30 mins and weighed at 256 grams.

CO2 Production in inputs

To account for the CO2 created durring the manufacturer of the sample we have to consider the inputs and their present and potential CO2 contributions.

- Electricity run pump -
    - The pump ran for 168 hours at 1.5 watts which equals 252 watt hours. In the US, 0.0007 kg is currently produced per Watt Hour.[12] So with current fossil fuel based energy production the energy used to run the pump produces 174 grams of CO2. However, using carbon free electrical generation the carbon from electrical usage would be zero.
- Calcium Chloride
    - Calcium chloride is the source of calcium in this sample. Calcium chloride is produced either by isolation from brine or by dissolving CaCo3 with HCL to produce CaCl2 and also CO2 emissions. There are other sources of calcium and magnesium that could be used with minimal CO2 production such as Walsonite. It could not be determined if the calcium chloride used was manufactured from brine or dissolving CaCo3.
- Cement produces Co2 in production via the energy used to heat and grind the CaCo3 and also in the Co2 produced in the chemical reaction. For Portland cement, its estimated .5 grams Co2 produced per gram of cement[13]. For the 34.5 gram sample, the

[11]SCD-30 NDIR CO2 Sensor, https://www.adafruit.com/product/4867. 2022. [online] Available at: <https://www.adafruit.com/product/4867> [Accessed 31 January 2022].
[12]EPA (2020) AVERT, U.S. national weighted average CO2 marginal emission rate, year 2019 data. U.S. Environmental Protection Agency, Washington, DC.
[13]

Co2 created is 17.25g. A further 17.25g are emitted via the heating and processing of the limestone; however this heating could be replaced via non CO2 generating sources.

Conclusion

Described here is a method for creating cast in place cement structures or cement based building materials that produce a higher compressive strength lightweight material that achieves quick complete carbonation. The carbonation sequers the CO2 released by the calcination of the cement durring production. The process may be able to continue sequestering CO2 and become a net sink for CO2.