Carbonation - The New Face of Concrete

Concrete in the built environment is quietly absorbing carbon dioxide from the atmosphere

By William Larson and Frank Came

PNBRC – January 2, 2019 - It's a process known to many in the construction sector, but not well understood. It's called 'carbonation' and means that concrete and mortar exposed to the air absorbs carbon dioxide (CO2) from the atmosphere.

Determining how much CO2 is absorbed per a given volume of exposed concrete has been difficult, in part because concrete varies significantly according to how and where it is used. Also, although many measurement approaches have been tried, a global consensus on how to measure carbonation remains elusive.

But one thing is clear – concrete in the built environment is a massive storehouse of carbon dioxide – so much so that if this reabsorbed CO2 were included in greenhouse gas accounting statistics it would alter the net emissions tallies of many nations.

The chemistry is quite straight forward. Concrete is the single most important building material in the world today, used for homes, schools, hospitals, bridges, tunnels, roads, and countless other construction projects large and small.

The most common cement type used to make concrete, Portland cement, is made by mixing limestone with other materials such as iron, alumina and silicon containing minerals, usually ground, mixed and burned at high temperature (1400-1450ºC) in a rotary kiln to form cement clinker.

The process of making cement is very carbon intensive. CO2 emissions from cement production are calculated both from the fuels used to heat the cement kiln and from the CO2 released from the raw carbonates used to make cement. This process is called calcination.

A widely quoted rough estimate is that cement and concrete use accounts for about 5 % of the world's carbon dioxide emissions. Often the story ends there, but in fact, the process of calcination is not chemically stable but reversible. This means that CO2 in the air reacts with hydrated cement in the concrete and carbonates are regenerated. This process is called carbonation.

Furthermore, the carbonated concrete is chemically stable so there is no risk that the CO2 that has been taken up will return to the atmosphere. This could only happen if the concrete is heated to a temperature where calcination can occur, i.e. about > 850 °C. This means that concrete in the built environment is an important and stable carbon sink.

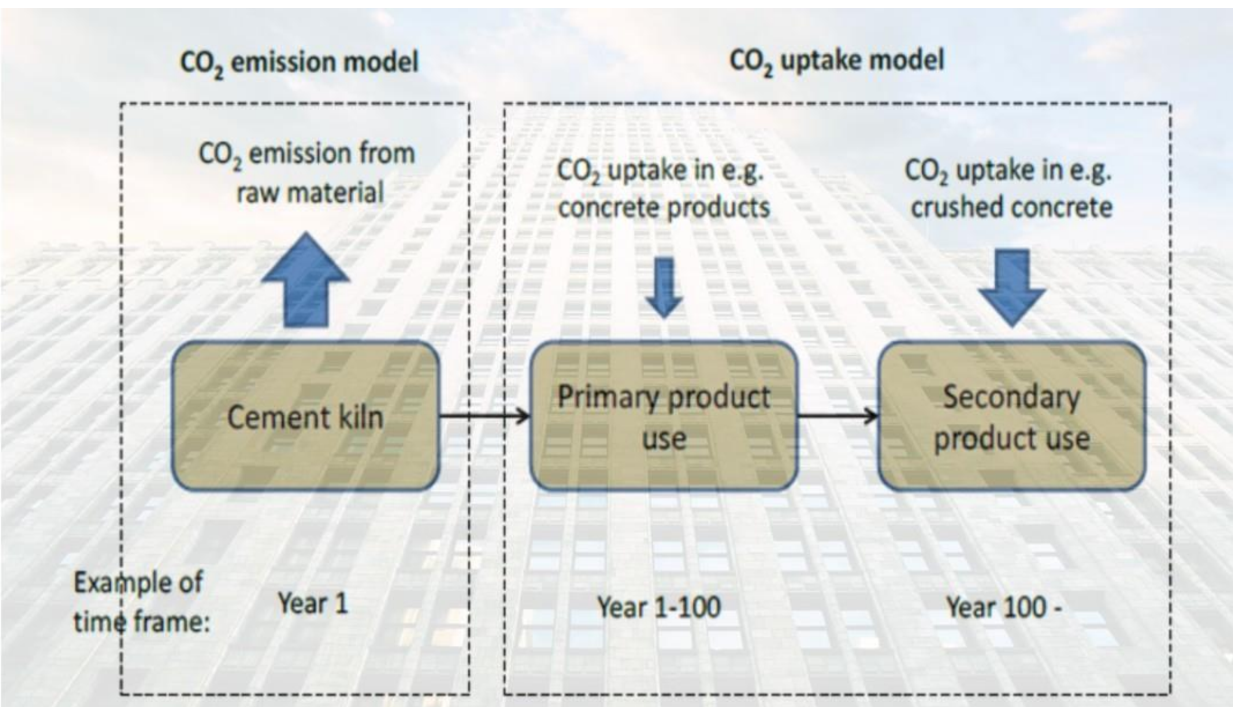

Figure 1 Schematic figure showing the CO_2 balance in cement containing products over a certain period of time.
Source: Swedish Environmental Research Institute

The carbonation process occurs not only over the lifetime of the concrete product, but also beyond its end of life. For example, crushed concrete used in road construction or as landfill material continues to absorb CO2 faster.

This uptake of CO2 in the concrete thus reduces the net emission of CO2 from cement production and from raw material usage. In principle, the same amount of CO2 given off in the cement kiln can be taken up by concrete through carbonation, though this depends on several factors such as time and exposure.

Given the enormity of concrete in use in the built environment, this uptake of CO2 can be significant, which is why it is important to take this effect into account in emission calculations.

Measuring Carbonation

A recent groundbreaking study by the Swedish Environmental Research Institute tackles the challenge of developing a model for measuring the CO2 uptake by concrete by examining the findings from several studies from European countries (Ireland, the Netherlands, Norway, Spain, Sweden, and Switzerland) as well as one major global report.

The goal was to develop a model that would enable CO2 uptake in concrete to become a part of the global CO2 net emission calculations. Three different calculations methods were developed of increasing complexity. The Tier 1 approach is a simplified calculation method that can be used by almost all national calculation groups with a minimum of input data.

The Tier 1 approach provides a simplified basis to estimate CO2 uptake by concrete using published estimates of cement production and concrete use. See Table below drawn from the original study.

Table 4 Calculated CO_2 uptake after 18 months (outdoors, sheltered from rain) in crushed concrete (1 m^3) separated into fractions, [14].

Size fraction (mm)	Relative amount	Paste		Cement* (kg)	Degree of carbonation (%)	CO_2 uptake** (kg CO_2/m^3 concrete)
		(%)	(kg)			
0 - 4 outer	0.5 × 0.25	25	75	53	55	14
0 - 4 inner	0.5 × 0.25	25	225	158	20	15
4 - 8	0.15	10	36	25	25	4
8 - 6	0.35	5	42	29	30	4
Total	1.0		378	265		37

* Paste, kg × 350/500. Cement 350 kg/m^3, Water 150 kg/m^3, w/c = 0.43 assumed (70 % of paste)

** Cement × Degree of carbonation × 0.49

Source: Swedish Environmental Research Institute

The presumption is that CO2 uptake in one year in a given region or country is related to the cement consumption in the same area and because cement consumption normally does not vary significantly over a few years, it is feasible to take the year of the reported CO2 emission from the material as basis for the uptake calculations.

Other research has confirmed that the first years of carbonation and CO2 uptake of a structure are most important. During the first 5 years, 22 % of the 100-years uptake takes place and 50 % of the 20-years uptake.

Leaving aside the complex mathematics and considering life time use, end of life disposition or reuse, the following examples were suggested in the study. It estimates that CO2 emissions from the production of 2 million tonnes of Portland cement would be 2,000,000 x 0.490 = 980,000 tonnes.

A rough estimate of CO_2 uptake through carbonation in concrete during the lifetime use, end-of-life and secondary use stages is (0.20 + 0.02 + 0.01) x 980,000 or 225,400 tonnes. A more conservative estimate of the CO_2 uptake during these three stages would be (0.15 + 0.02 + 0.01) x 980,000 = 176,400 tonnes.

As noted, given the massive scale of cement production and concrete use on a global scale, the level of CO_2 uptake through carbonation, even using the lower alternative of the simplified model, is staggering. The fact that carbonation is a stable process means that the built environment, as noted earlier, is a significant carbon sink that could alter the net emission tallies of many countries.

The study's authors caution that this simplified approach is fraught with uncertainties and more sophisticated models would be preferable. The Tier 2 model outlined in the study is more complex and can be used to calculate national estimates. The Tier 3 model uses complex computer models for the uptake calculations and requires more knowledge and input data. Such models have been developed in a few countries but only on a research basis.

Given that many organizations and companies are actively working on measures to reduce greenhouse gas reductions, having a better appreciation of the level of CO_2 uptake by concrete can help us develop strategies to mitigate the impacts of climate change.

As this and other studies clearly show, carbonation in cement products, represents a substantial carbon sink that is not currently considered in emissions calculations. Perhaps it is a necessity to look more closely at this process so that calculations of the net greenhouse gas emissions of the built environment can be as accurate as possible.

The full Swedish Environmental Research Institute study is available here.

About the Authors

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About the Pacific Northwest Building Resilience Coalition

The Pacific Northwest Building Resilience Coalition is a gathering of organizations, primarily in the cement, concrete and masonry industries, committed to furthering the planning, development, and construction of buildings and associated infrastructure better able to recover from and to adapt to the growing impacts of an ever-changing urban and physical environment.

Learn More about the Pacific Northwest Building Resilience Coalition here.