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carbonation

Quantifying a Sustainability Benefit of Concrete Pavement

Carbonation is One of Several Ways that Concrete Contributes to Sustainability

THERE HAS BEEN A GROWING EMPHASIS ON MAKING INFRASTRUCTURE MORE SUSTAINABLE AND RESILIENT, a movement accelerated by the Infrastructure and Investment in Jobs Act, which incentivizes the use of local materials such as concrete and funds investment in the decarbonization of such materials.

Due to its abundant use, concrete is often claimed to have a high carbon footprint. Most of its carbon emissions are associated with manufacturing portland cement, one of modern concrete's major components. Concrete is a long-lived material, which reduces the impact of the carbon produced during its manufacture over the extended service life. Carbonation is another way that concrete contributes to sustainability.*

» THE CARBONATION PROCESS

Over the life cycle of a concrete road, the potential for carbonation, although small, is significant. *How does it happen?*

1. During the production of portland cement, limestone consisting of calcium carbonate is added to the kiln.
2. When brought to a high temperature, the calcium carbonate ($CaCO_3$) converts to lime (CaO)—the product required for portland cement production—and CO_2, which is released into the atmosphere.
3. Once the portland cement is hydrated during and after construction, a partial reversal of the process begins. As the concrete surface is exposed to atmospheric carbon dioxide, the calcium hydroxide and calcium silicate hydrate in the hardened cement paste react chemically with the CO_2, converting back to limestone and recapturing the equivalent of some of the CO_2 that was emitted during production. This carbon capture is known as carbonation.

» HOW MUCH CARBONATION CAN OCCUR IN A TYPICAL U.S. CONCRETE PAVEMENT

Research by Anderson et. al quantified concrete's uptake of CO_2 by carbonation.[1]

There are several factors that determine the amount of carbonation taking place:

- Exposure (i.e., whether the concrete is exposed to rain, sheltered from rain, indoors, or underground)
- Amount of exposed concrete surface area
- Quality of the concrete
- Amount of cement

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An important observation is that concrete's rate of sequestration decreases with time because the calcium carbonate begins to fill up void space in the concrete. This "pore-blocking" effect slows the penetration of carbon dioxide into the concrete, so the rate of carbonation decreases at roughly the square root of time. The result is that about 45% of the carbonation that occurs over 50 years happens by year 10.

In a typical pavement, approximately 2-3mm of carbonation may occur in the first 2-3 years, whereas by year 20, the total depth of carbonation is only 5-8mm, with little additional carbonation occurring beyond year 50. The most practical way to counteract this decrease is to remove the carbonated surface and expose uncarbonated paste, an action most effectively accomplished through diamond grinding the pavement surface.

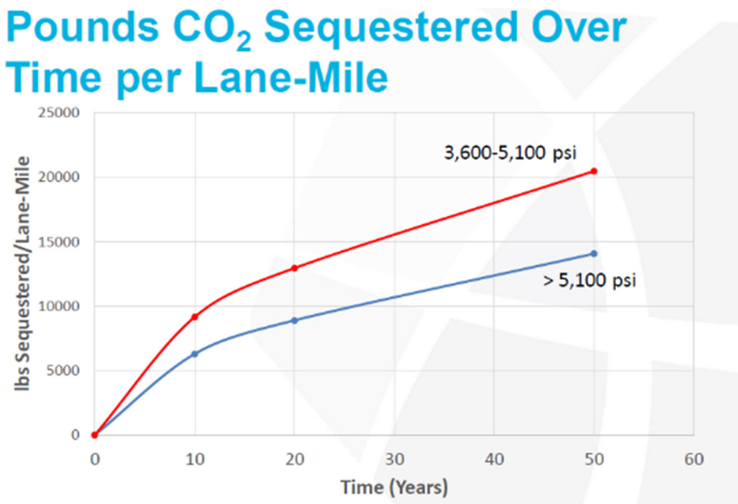

Fig. 1: Over a timespan of fifty years, concrete achieves carbonation of roughly 14,000-20,000 pounds per lane-mile.

Diamond grinding reopens the pore structure and exposes fresh calcium hydroxide and calcium silicate hydrate while also increasing surface area. Once a carbonated pavement surface is diamond-ground, the process of carbonation starts over. It's worth noting that a typical pavement reconstruction strategy—overlaying the concrete with asphalt—seals the pavement against atmospheric CO_2 and terminates sequestration.

» GETTING THE MOST SUSTAINABILITY BENEFIT FROM CONCRETE PAVEMENTS

Carbonization is one of several ways in which concrete's natural benefits can be optimized, but there is even more potential for concrete to help the planet and improve our daily lives.

- **Quality roads that will be around for generations:** Proper maintenance of a pavement extends pavement life and lessens the amount of new construction that would otherwise be necessary.
- **Preserves materials:** Less construction equates to less material acquisition and processing.
- **Reduces traffic congestion:** Less construction also means less traffic delays, thereby reducing vehicle greenhouse gas emissions.
- **Reduces greenhouse gas emissions:** It is well-documented that vehicle fuel efficiency is related to the smoothness of the pavement. Even considering there are some greenhouse gas emissions associated with concrete pavement preservation tasks (e.g., minor repair and diamond grinding), these are relatively small compared to those incurred due to rehabilitation or reconstruction. The overall ecological benefits of concrete pavement preservation, especially diamond grinding, are such that they likely offset the emissions due to the preservation activity.

» ACT PROACTIVELY AND THOUGHTFULLY

Conventional triggers and time frames for concrete pavement preservation may not optimize carbon capture or other concrete sustainability benefits. Currently, concrete pavement preservation featuring diamond grinding is most often performed when a pavement is showing advanced stages of distress. Typically, agencies and other road owners assess road roughness using the International Roughness Index (IRI) and often do not trigger treatment until a high IRI threshold value (180 in/mile or more) has been reached. According to studies performed by Wang et al., IRI trigger values should vary according to the amount of traffic on a given road to maximize sustainability benefits.[2]

With a more deliberate timing of preservation projects, the sustainability benefits of concrete pavement could be even greater than they currently are. Diamond grinding can be successfully performed on the same pavement multiple times. If diamond grinding were to be routinely performed on a 10-to-15-year cycle, vehicle-emitted carbon dioxide would be significantly reduced through improved smoothness and there would be a renewed rate of carbon dioxide sequestration. In fact, diamond grinding every 10 years would more than double the amount of sequestered CO_2 over a 50-year period. (See Fig. 2.)

Fig. 2: Diamond grinding pavement every ten years would more than double the amount of CO_2 sequestered over a fifty-year pavement life span.

Preserving concrete pavements to a high level of serviceability is inherently a sustainable solution. The above approach represents a rigorous quantification of the benefits of diamond grinding, making it easy to assess its advantages. Grinding concrete surfaces not only keeps them smoother and quieter, but also can more than double the amount of CO_2 sequestered over a 50-year design life. By comparison, carbonation would happen more slowly on unground pavement—and not at all on concrete once covered with asphalt.

» REFERENCES

[1]Anderson, et. al. 2019. "Carbonation as a method to improve climate performance for cement-based materials." Cement and Concrete Research, Vol. 124, (October 2019) 105819.

[2]Wang, et. al. 2013. "Network-Level Life-Cycle Energy Consumption and Greenhouse Gas from CAPM Treatments." Research Report: UCPRC-RR-2014-05. University of California Pavement Research Center, UC Davis, UC Berkeley http://www.ucprc.ucdavis.edu/PDF/UCPRC-RR-2014-05.pdf

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