Reduction of greenhouse gas emission by carbon trapping concrete using carboncure technology

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Abstract
The growing concern about climate change and global warming, resulting from the increased concentration of carbon-di-oxide in the atmosphere have created considerable interest in carbon sequestration. Carbon is usually sequestered in ocean or deep of the earth crust. but these processes require lot of time and need addition energy investment for carbon to be sequestered. It is noted that cement industries contribute to 7% of global CO₂ emission and its estimated that 50% of global cement production will be from India and China by 2050. Also, in current time when trees is being cleared for construction of building, which is estimated to release 1.5 billion ton of CO₂ into our atmosphere every year. Some measures must be taken to give back to the environment. Thus, if carbon is stored in concrete, it is likely to stay for longer time. The carbon cure technology enables the production of some reliable concrete but with reduced carbon footprint. The technology injects a precise dosage of CO₂ in concrete during mixing where it mineralizes. The mineralized CO₂ improves the concrete compressive strength, enabling reduced cement content in their mixes and achieve further carbon reduction without compromising quality. Concrete made with carbon cure technology provides 4-6% reduction to global warming potential

Keywords: CO₂; Global Warming; Concrete; Greenhouse Gas;

1. Introduction
The causes of recent global warming are still being subjected to research. However, there is a scientific consensus which identifies human activity as the main influence of greenhouse gasses which have been verified over 50 years. The emission generated from the manufacturing and transportation of building material is known as embodied carbon. The construction and building sector generate 39% of world greenhouse gas emission, and over a quarter of these emission come from embodied carbon. There is a need to decline of carbon emission by 65% by 2030 and be eliminated by 2040. If we don’t reach these goals, we will have lost the opportunity to meet what climate scientists have deemed a vital global warming threshold of 1.5°C above pre industrial levels. According to the International
Panel on Climate Change (IPCC), once the threshold is exceeded, climate change will become irreversible, resulting in greater economic instability, a reduction in wealth, and a reduced demand for construction.[3]

The global annual emission of CO$_2$ was about 23.5 Gigaton CO$_2$/yr in 2000 – IPCC (Intergovernmental Panel on Climate Change), 2005. The concentration of CO$_2$ in the atmosphere has increased progressively since the beginning of the Industrial Age by about 30% from 280 (1750) to 367 ppm (1999) – 2001[2]. In order to prevent a major climate change, the atmospheric CO$_2$ concentration should be stabilized by either increasing the (biological) CO$_2$ up-take from the atmosphere or reducing the CO$_2$ emissions.

Three major approaches for reduction of CO$_2$ emissions can be distinguished:

1. Reduction of the energy consumption based on fossil fuels.
2. Energy generation by non-fossil sources such as solar, wind, biomass, and nuclear energy.
3. Carbon capture and storage (CCS). In CCS-technologies, CO$_2$ is separated from the flue gas of a stationary CO$_2$ source, such as a fossil fuel-based power plant, and subsequently stored for long-term isolation from the atmosphere.

Concrete is one of the world's most abundant materials, and a crucial frontier in the flight against climate change. The production of Portland cement and key ingredients that bind the concrete gives strength, accounts for approximately 7% of global CO$_2$ emission. The cement industry has previously recognized a number of approaches to reduce the emission intensity of cement produced and used in concrete with the industry goal to reduce emission 50% below by 2050. It is clear, however that practical limits on these measures mean that meeting the goal will be difficult. Innovative approaches are sought and likely to be a part of portfolio strategy. The most significant improvement in production efficiency and cement substitution with supplementary cementitious material are already known and available.[4] Future emission improvements will likely to be incremental. Therefore, innovative approaches are sought that can be part of portfolio system. One such innovative approaches is carbon cure technology it introduces carbon dioxide (CO$_2$) into a fresh concrete in order to improve the concrete compressive strength and enable concrete producers to optimize their mix designs. By using CO$_2$ to enhance strength, it is able to achieve up to a 7% reduction in cementitious content, which results in significant cost savings[5] The technology is retrofitted into existing ready-mix facilities without disrupting operations. Batching is controlled by producers batching software in the same manner as admixtures.

Addressing the continuous rise of atmospheric carbon dioxide levels has become a focus of global efforts. Research in carbon capture and storage (CCS) has increased substantially in the last decade[5]. Current carbon storage research has been primarily concentrated on sequestering CO$_2$ in underground geologic formations such as saline aquifers, depleted oil and gas fields, and unmineable coal seams. These methods of geologic sequestration have the advantage of being relatively low cost when separated from CO$_2$ capture, separation, and transportation. However, potential issues associated with sequestration in geologic formations include: permanence, long-term monitoring, and verification, with many unknown effects and potential risks still to be determined[6]. An alternative to conventional geologic sequestration is carbon mineralization, where CO$_2$ is reacted with metal cations such as magnesium, calcium, and iron to form carbonate minerals.
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Need For Carbon Tarping Concrete
Concrete is the most abundant human-made material on the planet because its ingredients are widely available and result in a product that is incredibly strong, resilient, and effective in construction. There is no credible alternative to concrete, so innovation in concrete offers the biggest potential for CO$_2$ reduction in the built environment.

By 2060, 230 billion square metres of new buildings will be constructed, effectively doubling the current worldwide building stock. In the next ten years, most of that construction will take place in the Global North and China. In the Global South where much of the infrastructure is yet to be built, the demand for concrete will be even higher over the next 40 years.

The time value of carbon — i.e. the amount of carbon reduction and when the reduction can happen — is critical here since the materials used in these projects will be manufactured in the near-term. Once carbon is emitted in the manufacturing process, it is difficult and expensive to recover it. CO$_2$ emissions that are reduced today are more valuable than CO$_2$ emissions reductions that occur in the future given the radioactive impact of global warming.

2. Materials and Methods

2.1 Cement
Cement is a binding material with adhesive and cohesive properties which make it capable of bonding mineral fragment into a compact whole. The ordinary Portland cement / the type of cement specified in mix design is used.

Chemical composition of ordinary Portland cement (Table 1)

<table>
<thead>
<tr>
<th>OXIDE</th>
<th>CONTENT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime (CaO)</td>
<td>60-67</td>
</tr>
<tr>
<td>Silica (SiO$_2$)</td>
<td>17-25</td>
</tr>
<tr>
<td>Alumina (Al$_2$O$_3$)</td>
<td>3-8</td>
</tr>
<tr>
<td>Iron Oxide (Fe$_2$O$_3$)</td>
<td>0.5 – 6</td>
</tr>
<tr>
<td>Magnesia (MgO)</td>
<td>0.1 – 4</td>
</tr>
<tr>
<td>Sulphur trioxide (SO$_3$)</td>
<td>1.3 – 3</td>
</tr>
<tr>
<td>Alkalies (K$_2$O, Na$_2$O)</td>
<td>0.4 – 1.3</td>
</tr>
</tbody>
</table>
2.1 Fine Aggregate
The aggregate passing through IS sieve 4.75 mm size is termed as fine aggregate. The sum of percentage of all type of deleterious material in fine aggregate should not exceed 5%. The natural sand or crushed stone dust (m sand) is the fine aggregate mainly used in concrete.

2.2 Coarse Aggregate
The aggregate retained in IS sieve 4.75 mm size is termed as coarse aggregate. The size of coarse aggregate used depends on mix design and nature and type of work required.

2.3 Water
Portable water must be used.

2.4 Carbon Dioxide
Carbon dioxide is sourced from industrial emitters. Established gas suppliers collect, purify and distribute the CO₂. The CO₂ is stored at concrete plants in pressurized tank that are refilled regularly by gas suppliers.

Carbon capture involves collecting CO₂ either from its original emission source or directly from the air. By itself, the process of capturing CO₂ does not provide a climate benefit unless the captured carbon is utilized or stored. Most CO₂ that is collected today is captured as a by product from industrial sources (e.g. ethanol, ammonia, and refineries). The food and beverage industry is the largest consumer of post-industrial captured CO₂ despite it not having a climate benefit since it is immediately re-released.

2.6. Carbon capture and storage
2.6.1. Post-combustion capture
This process involves the removal of CO₂ from the flue gas after the combustion of the fuel in the kiln. Figure shows the schematic for post-combustion capture. There are multiple methods for capturing CO₂ from flue gas including chemical absorption, membrane separation, and carbonate looping.
Chemical absorption, also known as carbon scrubbing, seems to be the most promising approach and closest to commercialization as having high CO\textsubscript{2} capture rates in other industries. The absorption process makes use of the easily reversible chemical reaction of CO\textsubscript{2} with an aqueous alkaline solvent, usually amines, potassium, or other chemical solutions. Membrane separation is the process of using synthetic membranes made from polymers to capture CO\textsubscript{2} as it passes through.

[Diagram of Post-Combustion Capture]

2.6.2. **Oxyfuel combustion**
This technique would use oxygen in cement kilns instead of air. Figure shows the schematic for oxyfuel combustion. This would have a result of a comparatively pure CO\textsubscript{2} stream. This stream of CO\textsubscript{2} would then be ready to store.

[Diagram of Oxyfuel Combustion]

2.6.3. **Pre-combustion capture**
This process has many issues associated with it for the implementation on combustion kilns. The main issue is the presence of pure hydrogen in the process. This, combined with the clinker-burning process would require heavy modifications to the cement making process in order for safe usage.

2.6.4. **Direct air capture (DAC) is a process of capturing CO\textsubscript{2} directly from the ambient air.** DAC is still in the early stages of development but has shown promise and will help accelerate growth in the carbon capture space. DAC will also enable the capture of carbon in areas where it is not possible today. Once captured, in order to achieve an environmental benefit, the CO\textsubscript{2} must either be stored permanently (sequestration) or converted into valuable products (utilization).
Fig 4. Direct Air Capture of Carbon dioxide

3. **Manufacturing Process**

![Diagram of the manufacturing process involving Coarse Aggregate, Fine Aggregate, Cement, Water, Carbon dioxide, Control box, Valve box, and Mixers.](image-url)
3.3.1 Manufacturing process of carbon trapping concrete using carboncure ready mix concrete technology

FLOW DIAGRAM: Process involved in carboncure technology

Carbon cure technology is retrofitted to an existing concrete plant

Carbon dioxide (CO$_2$) gas is primarily sourced as a by-product from industrial process.

The purified CO$_2$ gas is delivered in pressurized vessels by commercial gas

Carbon cure proprietary delivery system precisely injects the CO$_2$ into the concrete mix

Batching is controlled by a simple interface integrated with the batch

Once injected CO$_2$ reacts with the cement to form a nano sized minerals that become permanently embodied in concrete

4. Results and discussion

4.1 Effect Of CO$_2$ On Concrete Properties

The testing is done between a reference concrete batch and a batch subjected to CO$_2$ addition. Concrete durability test results indicated that the carbon dioxide process did not compromise the expected performance of the treated concrete. Batches of concrete were prepared for which the slump
and air content were measured both before and after the addition of CO₂. It was found that the carbon dioxide had little to no effect on the air content and slump of the concrete.

![Fig 5. Effect of CO₂ added concrete on slump](image)

![Fig 6. Effect CO₂ added concrete on air content](image)

**Table 2. CO₂ Impact on concrete properties**

<table>
<thead>
<tr>
<th>Fresh Properties</th>
<th>Hardened Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting time</td>
<td>Freeze - thaw</td>
</tr>
<tr>
<td>Workability/slump</td>
<td>pH</td>
</tr>
<tr>
<td>Concrete pumping</td>
<td>Density</td>
</tr>
<tr>
<td>Air content</td>
<td>Colour</td>
</tr>
<tr>
<td>temperature</td>
<td>Durability</td>
</tr>
<tr>
<td>finishing</td>
<td>Texture</td>
</tr>
</tbody>
</table>

**Effect of CO₂ on pH and corrosion:**

Weathering carbonation occurs in concrete when calcium hydroxide compounds react with CO₂ from the atmosphere and form solid calcium carbonate. The depletion of calcium hydroxide will cause the concrete pore solution pH to drop below 13, which can cause rebar corrosion. When CO₂ is injected into fresh concrete using the Carboncure Technology, the CO₂ reacts immediately with cement to form a solid calcium carbonate mineral. Calcium carbonate does not impact rebar corrosion. Research has shown that a CO₂ utilization process has a negligible effect on the pH of the pore solution of mature concrete, and therefore suggests no risk of rebar corrosion.

**Effect of CO₂ on compressive Strength**

Carboncure has been observed to provide ready mix concrete compressive strength improvements by up to 10% through and beyond 28 days. The improvements can be leveraged to support a reduction of cementitious material in the mix design without compromising on strength performance.
**Effect of CO$_2$ on flexural strength**

It has been observed that CO$_2$ added concrete mix with a cement reduction has an comparable flexural strength to an unmodified control mix after 28 days. The flexural strength of concrete is maintained with addition of CO$_2$.
It is estimated that the global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions, according to the IPCC report. The Earth’s average temperature data showed a warming of 0.85°C over the period 1880 to 2012. It was 0.87°C for the decade 2006-2015. Most of the warming occurred in the past 35 years, with 16 of the 17 warmest years on record occurring since 2001. The planet's average temperature has risen about 1.1°C since the late 19th century, according to analyses by scientists at NASA's Goddard Institute for Space Studies. The world has seen the consequences of this 1°C rise in temperature through more extreme weather, rising sea levels and diminishing Arctic Sea ice, among other changes in the last few years [21].

Some companies are taking on the rest of the equation by pursuing technologies to mitigate the climate change that can capture the carbon dioxide resulting from concrete production: Lafarge Holcim, the multinational construction materials manufacturer, in July 2019 launched a project to capture and reuse CO$_2$ from a cement plant and is expected to replace 50 percent of fossil fuel usage and reduce emissions by 20% [22].

Christie Gamble, CarbonCure’s director of sustainability, says that if the technology were to be adopted universally, it could lock away 700 million tonnes of CO$_2$ every year. One 12-story building recently completed in Atlanta, made with CarbonCure treated concrete, contains 1.5 million pounds of sequestered CO$_2$ [22].

up to 70 percent of that CO$_2$. Not only does the process save on water—which is also a selling point in arid regions—but the curing process is complete in just 24 hours [22].

Finally, Blue Planet of Los Gatos, Calif., has developed a process that converts flue gas into a solid carbonate coating that is then applied to small pebbles (made from upcycled demolition debris). The resulting synthetic limestone is 44 percent carbon dioxide by mass. Because these pebbles themselves are carbon negative, adding them to concrete can offset the CO$_2$ emitted by other parts of the concrete manufacturing process. Depending on other factors, concrete using those pebbles as aggregate can be net carbon neutral or even carbon negative [22].
Applications
CarbonCure for Ready Mix: CO₂ injected via CarbonCure improves the compressive strength of ready mix concrete, which enables ready mix producers to optimize their mix design while reducing the carbon footprint of their concrete.
CarbonCure for Masonry: CO₂ sequestered via CarbonCure reduces the carbon footprint of concrete masonry, which enables masonry producers to differentiate their CMU brand and increase sales with the growing green building market.
CarbonCure for Precast: CO₂ injected via CarbonCure improves the compressive strength of precast concrete, which allows precast producers to further optimize their mix designs and reduce the carbon footprint of the precast products they provide.

Conclusion
With global population on rise the demand for concrete increasing, the need for reducing the CO₂ emission has become very apparent. Although the technology is new, carbon capture and permanent storage in concrete is paving the way for future of CO₂ sequestration. The CO₂ injecting into the concrete mix during mixing is the best method of sequestering the CO₂ for permanent storage in the concrete. This reduces the cost and risk associated with the traditional storage method of transporting the CO₂ to rural underground storage reservoirs. Injection of CO₂ gets mineralized into calcium carbonate which will never released even after demolition. Studies show that CO₂ has increased the compressive strength of mix design, while decreasing the need for cement. This decrease in cement will overall reduce the production that emits CO₂. The CO₂ will not have any undesirable effect on fresh and hardened properties of concrete. This technology will lead to the reduced carbon footprint with green buildings

References
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