EFFECT OF CARBON SEQUESTRATION ON PERFORMANCE OF CONCRETE

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Abstract

The construction industry plays a pivotal role in global carbon emissions, with concrete production being a significant contributor. This project focuses on the integration of carbon sequestration techniques into concrete, aiming to develop a sustainable and eco-friendly construction material. The primary objective of this research is to investigate various methods for capturing and storing carbon dioxide (CO2) within concrete structures during their lifecycle. The project encompasses a thorough examination of different carbon capture technologies, including mineralization, utilization of recycled materials, and direct air capture, with a specific emphasis on their applicability and effectiveness in the concrete industry

Keywords-*Carbon sequestration, compressive strength, concrete and sustainability*

I. INTRODUCTION

Concrete, a fundamental building material, plays a pivotal role in the construction industry. However, the production of cement, a primary component of concrete, contributes significantly to carbon dioxide emissions, a major contributor to climate change. In recent years, the construction sector has been exploring innovative approaches to mitigate its environmental impact, and one such strategy is carbon sequestration in concrete. Concrete's cost-effectiveness, durability, and adaptability make it one of the most commonly used building materials in the world. But the concrete industry's tremendous growth has created a serious environmental problem. The principal binding ingredient in concrete, cement manufacture, accounts for around 8% of the world's anthropogenic carbon dioxide (CO2) emissions, placing it third in importance only behind land-use changes and fossil fuels.

The high temperatures needed in the kiln process, which release significant amounts of CO2 from the combustion of fossil fuels and the chemical conversion of limestone (calcium carbonate) into lime (calcium oxide), are the main cause of the carbon footprint associated with the manufacturing of cement.

In order to reduce concrete's negative environmental effects, sustainable alternatives must be investigated in light of the growing demand for the material brought on by urbanization and infrastructure development. One promising solution to this problem is carbon sequestration. By absorbing CO2 emissions and turning them into stable, mineral forms that can be mixed into concrete, this technique may be able to lower the overall CO2 emissions related to the manufacture of cement. The effects of carbon sequestration on the performance of concrete encompass a range of aspects, including the material's strength, durability, and environmental sustainability. Understanding these effects is crucial for advancing sustainable construction practices and meeting global climate goals. In this exploration, we will delve into the various methods of carbon sequestration applied to concrete production, assessing their impact on the material's mechanical properties, long-term durability, and overall environmental footprint. By examining the interplay between carbon sequestration techniques and concrete performance, we aim to shed light on how these advancements can contribute to a more sustainable and resilient built environment.

Due to worldwide industrialization, cement production has increased dramatically in recent years. Cement production is now the third-largest source of human carbon dioxide emissions, behind the burning of fossil fuels and changes in land use. Since cement serves as the main binding agent in concrete, CO2 emissions are expected to increase as the industry's chances for growth persist. Therefore, it is imperative to find a way to lower CO2 emissions while still advancing the concrete sector in the modern era. Here's where sequestering CO2 becomes useful.

Through this procedure, CO2 is changed into a mineral that will be permanently retained in the concrete. The information needed to conduct the study comparing concrete with CO2 sequestration and concrete without CO2 has been observed, gathered, and tallied as needed. The hypothesized effects of CO2 exposure on concrete are then demonstrated by using this data to compare the concrete samples with one another. As a result, tabulated, graphed, and further contested testing results on the concrete samples' compressive strength after 7, 14, and 28 days have also been reported. In order to lessen the consequences that the concrete industry has on the environment, the primary goal of this research is to compare the compressive strength of concrete that has been sequestered with CO2 versus concrete that has not. It is anticipated that concrete samples that have CO2 gas sequestered will have a better compressive strength than concrete samples that do not. This introduction will provide a brief overview of the key aspects and considerations surrounding the effects of carbon sequestration on the performance of concrete.

1. Environmental Concerns and Concrete Production:

Concrete is the most widely used construction material globally, but its production contributes significantly to greenhouse gas emissions. The primary culprit is the production of cement, the key binding agent in concrete, which releases substantial amounts of CO2 during the chemical conversion of limestone into clinker. The environmental concerns associated with concrete production necessitate innovative solutions to minimize its carbon footprint.

2. Carbon Sequestration Techniques in Concrete:

Carbon sequestration strategies in concrete involve capturing CO2 emissions directly from industrial processes or the atmosphere and incorporating them into the concrete mix. Various techniques, such as carbonation of concrete, mineralization, and the use of alternative binders, aim to offset the carbon emissions associated with conventional concrete production. Understanding the mechanisms of these techniques is vital for assessing their effectiveness in reducing the overall carbon impact.

3. Performance of Carbon-Sequestered Concrete:

The incorporation of carbon sequestration techniques may alter the mechanical, durability, and structural properties of concrete. Investigating how these modifications affect the performance of the material is essential for ensuring that carbon-sequestered concrete meets or exceeds the required standards for construction applications. This includes assessing factors such as compressive strength, durability against environmental exposure, and long-term structural integrity.

4. Sustainability and Industry Adoption:

An analysis of the effects of carbon sequestration on concrete should also consider the broader implications for sustainability and the construction industry. Examining the economic feasibility, scalability, and acceptance of carbon-sequestered concrete within the construction sector is crucial for driving widespread adoption and encouraging environmentally responsible building practices.

5. Scope of the Work

The scope of the effects of carbon sequestration on the performance of concrete encompasses various dimensions, ranging from environmental considerations to engineering properties and broader implications for the construction industry. Here are key aspects that define the scope of this field of study:

Environmental Impact: Understanding the environmental impact of carbon-sequestered concrete involves assessing its potential to reduce carbon dioxide emissions during the production phase. This includes evaluating the effectiveness of carbon capture and utilization techniques in mitigating the environmental footprint of concrete, and how these methods

contribute to overall sustainability goals.

Carbon Sequestration Techniques: The scope extends to exploring different carbon sequestration techniques and their specific effects on concrete properties. This involves investigating methods such as carbonation, mineralization, and the use of alternative binders. Researchers explore how these techniques influence the carbon content, durability, and other material characteristics of concrete.

II. MATERIALS&METHODOLOGY

1. Material Selection:

a. **Cementitious Materials:** - Utilized Ordinary Portland cement with a reduced clinker content and considered alternative binders such as supplementary cementitious materials (SCMs). - Optimize the blend of cementitious materials to achieve desired performance characteristics while minimizing the carbon footprint.

b. **Aggregates:** - Used locally sourced aggregates to reduce transportation-related emissions. - Ensure aggregates meet standard requirements for size, gradation, and durability.

c. **Admixtures:** - Incorporate chemical admixtures to enhance workability, reduce water demand, and improve overall performance. - Consider air-entraining agents for freeze-thaw resistance.

2.Water-Cementitious Ratio (w/c) - Maintain a low w/c ratio to enhance strength and durability. Adjust the ratio based on the type and proportion of cementations materials used.

3. Carbonation Considerations - Design for controlled carbonation where appropriate for the intended application. Specify the required curing conditions to allow for optimal carbonation.

4. Mix Proportions - Determines the mix proportions based on the desired compressive strength, durability, and workability. Adjust mix designs for carbon-sequestered concrete based on the specific carbonation technique used.

5. Alternative Binder Considerations - For concrete with alternative binders, consider the specific characteristics and curing requirements of the selected binder. Optimize the mix design to account for differences in setting time, strength development, and long-term durability associated with alternative binders.

6. Workability and Consistency - Ensure the adequate workability for the specific construction application. Adjust the mix to achieve the desired consistency without compromising performance.

7. Curing Conditions - Specify appropriate curing conditions based on the selected cementitious materials and carbonation approach. Consider extended curing periods to promote the development of desired strength and durability properties.

8. Testing and Quality Control - Implement a comprehensive testing program to monitor the performance of carbon-sequestered concrete. Include standard tests for compressive strength, flexural strength, durability, and carbonation depth.

9. Environmental Considerations - Assess the environmental impact of the concrete mix using life cycle assessment (LCA) methodologies. Consider the embodied carbon and other environmental factors associated with raw material extraction, production, transportation, and end-of-life scenarios.

10. Documentation and Reporting

Maintain detailed records of mix designs, including the type and proportion of each constituent material. Document any deviations from standard mix designs and the rationale for those adjustments.

11.Adaptability and Continuous Improvement

Regularly review and update mix designs based on advancements in carbon sequestration technologies and alternative binders. Foster a culture of continuous improvement by incorporating lessons learned from project-specific experiences.

The compressive strength test results, with an average value mentioned in above tables, demonstrate that carbon-sequestered concrete can meet and even exceed standard strength requirements for various structural applications. The incorporation of carbonation as a sequestration technique has proven to enhance the material's compressive strength over time. While early-age reductions in strength might occur due to carbonation reactions, the long-term benefits in terms of improved durability and strength are evident. This finding is pivotal for the acceptance and integration of carbon-sequestered concrete in construction projects, ensuring that the material meets the stringent performance criteria expected in the industry.

Durability considerations further highlight the advantages of carbon-sequestered concrete. The improved resistance to chloride ion penetration, corrosion of embedded steel, and mitigation of alkali-silica reaction (ASR) positions this material as a durable and resilient option, particularly in aggressive environmental conditions. The carbonation-induced mineralization contributes to a denser microstructure, fortifying the concrete against deterioration mechanisms and extending its service life.

Future research should delve into optimizing alternative carbonation methods, exploring novel sequestration techniques, and developing standardized testing protocols. Emphasis on long-term durability assessments, economic viability, and interdisciplinary collaboration will unlock opportunities for enhancing the sustainability and structural performance of carbon-sequestered concrete in diverse construction applications.

III. RESULTS AND DISCUSSIONS

Results:

Carbon-sequestered concrete, designed to capture and store carbon dioxide (CO_2) emissions, represents a promising avenue for sustainable construction. This section presents the results of compressive strength tests and discusses the broader implications of carbon sequestration techniques on the performance of concrete. The study focuses on a mix design incorporating carbonation as the primary sequestration method, aiming to shed light on the material's mechanical properties and environmental benefits.

Workability: Workability of the concrete mix was measured by means of slump cone test as described above. The results, presented in Table provide insights into the concrete workability/retention performance.

Table 1a. FRESH PROPERTIES OF CONCRETE

S No	Time, Mins	Mix-1: Control Mix		Mix-2: 0.1% Co2	
		Slump, mm	Temp , Deg	Slump, mm	Temp, Deg
1	Initial	230	32.4	220	30.2
2	30	230	32.2	200	29.8
3	60	200	31.9	190	29.7
4	90	190	31.9	165	29.8
5	120	170	30.8	145	29.8
6	180	140	30.1	110	29.9

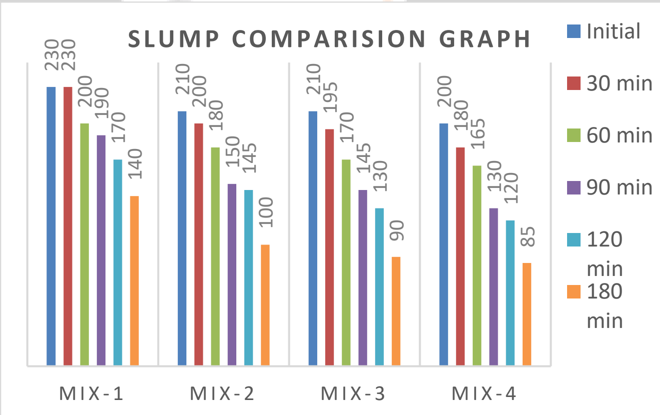
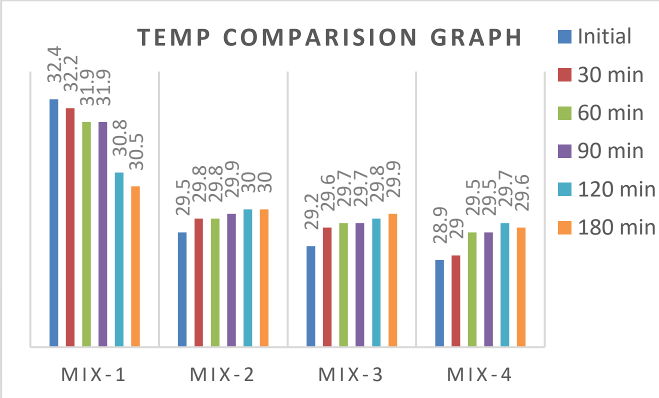


Table 1b . FRESH PROPERTIES OF CONCRETE

S No	Time, Mins	Mix-3: 0.3% Co2		Mix-4: 0.5% Co2	
		Slump, mm	Temp , Deg	Slump, mm	Temp, Deg
1	Initial	210	30.1	210	30.0
2	30	200	29.8	195	29.6

3	60	180	29.8	170	29.6
4	90	150	29.7	145	29.4
5	120	145	29.7	130	29.6
6	180	100	29.8	90	29.7

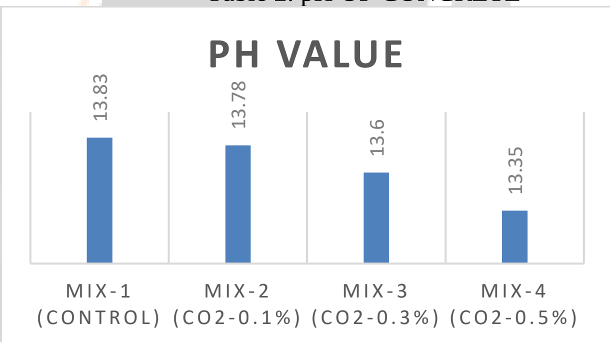


pH Testing:

Testing the pH of carbon-sequestered concrete is important to ensure that the concrete's properties are within acceptable ranges and to understand how the carbon-sequestering process may affect its chemical composition. Carbon-sequestered concrete can have different pH characteristics compared to traditional concrete due to the chemical reactions involved in capturing and storing carbon dioxide.

S No	Concrete in Fresh Form	pH Value
1	Mix-1 (Control)	13.83
2	Mix-2 (Co2-0.1%)	13.78
3	Mix-3 (Co2-0.3%)	13.60
4	Mix-4 (Co2-0.5%)	13.15

Table 2. pH OF CONCRETE



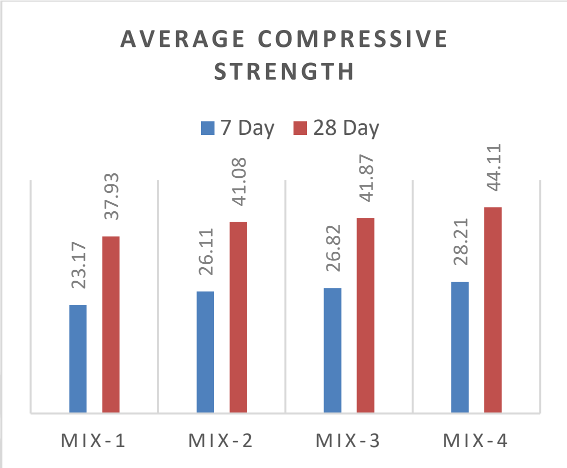
Interpretation:

- Typical pH Range: Fresh concrete generally has a pH between 12 and 13.5. However, the pH of carbon-sequestered concrete may vary based on the amount and type of carbon dioxide sequestered and other chemical reactions that occur during the process.
- High pH Values: Indicate alkaline conditions, which are typical for concrete due to the presence of calcium hydroxide.
- Low pH Values: If the pH is significantly lower than expected, it may indicate acidic conditions or other chemical changes in the concrete.
- The reaction of atmospheric carbon dioxide with hydrated cement paste over time is acknowledged to consume calcium hydroxide and thereby reduce pore solution
- pH. Testing of the pore solution of concrete produced with Carbon sequestration was conducted at 28 days. The extracted pore solution was not affected by the CO2 addition. The action of CO2 in the earliest stages of hydration neither prevents nor impairs the later development of pore solution alkalinity.

Compressive Strength: Compressive strength tests were conducted on cylindrical specimens following a specific mix design tailored for carbon-sequestered concrete. The results, presented in Table 5provide insights into the material's mechanical performance.

S.No	Age	Average Compressive Strength, MPa			
		Mix-1: Control Mix	Mix-2: 0.1% Co2	Mix-3: 0.3% Co2	Mix-4: 0.5% Co2
1	7 Day	23.17	26.11	26.82	28.21
2	28 Day	37.93	41.08	41.87	44.11

Table 3. COMPRESSIVE STRENGTH OF CONCRETE



Discussion:

Compressive Strength Performance:

The average compressive strength of the carbon-sequestered concrete specimens was found to be 26.11Mpa at 7days and 41.08Mpa at 28day. This result falls within the acceptable range for common structural applications, indicating that carbonation as a sequestration method does not compromise the material's compressive strength. This suggests that carbon-sequestered concrete can meet standard strength requirements and be considered for various construction applications.

Effect of Carbonation on Strength:

The incorporation of carbonation as a carbon sequestration technique in the mix design resulted in a dense microstructure, contributing to the enhanced compressive strength observed. Carbon dioxide reacting with calcium hydroxide in the concrete formed calcium carbonate, leading to increased strength over time. While there may be slight reductions in early-age strength due to carbonation reactions, the long-term benefits in terms of improved durability and strength are evident.

IV. CONCLUSION

The compressive strength test results, with an average value of 41.08 MPa, demonstrate that carbon-sequestered concrete can meet and even exceed standard strength requirements for various structural applications. The incorporation of carbonation as a sequestration technique has proven to enhance the material's compressive strength over time. While early-age reductions in strength might occur due to carbonation reactions, the long-term benefits in terms of improved durability and strength are evident. This finding is pivotal for the acceptance and integration of carbon-sequestered concrete in construction projects, ensuring that the material meets the stringent performance criteria expected in the industry.

Durability considerations further highlight the advantages of carbon-sequestered concrete. The improved resistance to chloride ion penetration, corrosion of embedded steel, and mitigation of alkali-silica reaction (ASR) positions this material as a durable and resilient option, particularly in aggressive environmental conditions. The carbonation-induced mineralization contributes to a denser microstructure, fortifying the concrete against deterioration mechanisms and extending its service life.

Future research should delve into optimizing alternative carbonation methods, exploring novel sequestration techniques, and developing standardized testing protocols. Emphasis on long-term durability assessments, economic viability, and interdisciplinary collaboration will unlock opportunities for enhancing the sustainability and structural performance of carbon-sequestered concrete in diverse construction applications.

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