GLOBAL RESEARCH IMMERSION PROGRAM FOR YOUNG SCIENTISTS

A PROSPECTIVE APPROACH FOR ENHANCING THE PERFORMANCE OF CARBON-MIXED CONCRETE VIA RETARDER INCORPORATION

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Background

Global warming, driven by greenhouse gas emissions, is one of the most significant environmental challenges today. Carbon dioxide (CO2) contributes approximately 50% to the greenhouse effect, with industrial production, particularly the cement industry, being a major source of CO2 emissions. As a leading cement producer, China is at the center of global discussions on carbon emissions. Carbon Capture Utilization and Sequestration (CCUS) technologies, such as CO2 mineralization in cement, have become effective methods for reducing carbon emissions in the cement industry. This study investigates the effects of incorporating CO2 during the mixing process of concrete (carbon-mixed concrete, CMC) and the addition of a retarder to enhance its performance and workability.

Material & Method

Materials:

1. Cement: Ordinary Portland Cement (PO 42.5 grade)
2. Aggregates: Crushed stone A (5-31.5 mm), Crushed stone B (5-16 mm)
3. Fine Aggregates: Natural river sand, manufactured sand
4. Admixtures: Fly ash, mineral powder, calcium lignosulfonate (CL)
5. Carbon dioxide: Supplied by Hangzhou Hangxiang Gas Co., Ltd.

Experimental Setup:

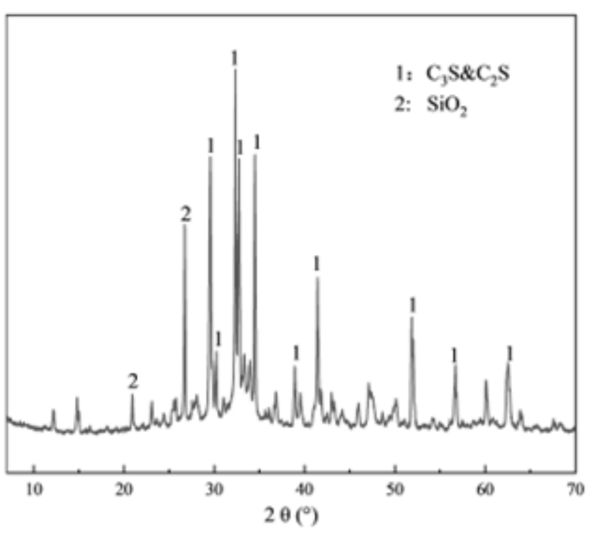
- A novel CMC mixing device with a mixer, mixing cover, flow meter, concentration sensor, and pressure gauge was developed to ensure efficient CO2 absorption.

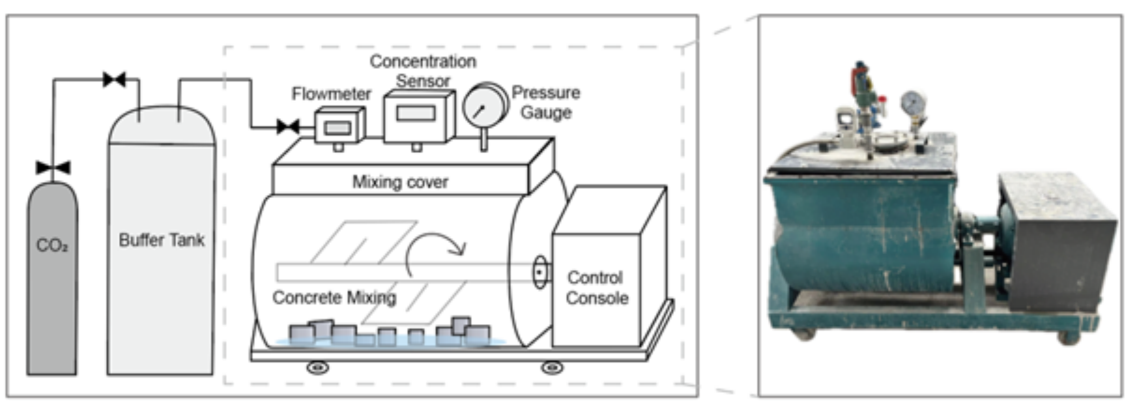
Mix Design:

- Concrete mix proportions per cubic meter: Cement (270 kg), mineral powder (56 kg), fly ash (54 kg), manufactured sand (665 kg), natural sand (160 kg), crushed stone A (770 kg), crushed stone B (180 kg), and water (173 kg).
- Water-cement ratio: 0.42.

Experimental Procedures:

1. Dry mixing of aggregates, cement, fly ash, and mineral powder for 30 seconds.
2. Addition of water mixed with CL, followed by uniform mixing.
3. Introduction of CO2 gas into the mixer and sealing for efficient absorption.
4. Slump test to assess flowability, and compressive strength tests at 3, 7, 28, and 56 days.
5. Microstructural analyses: Mercury Intrusion Porosimetry (MIP), Thermogravimetric Analysis (TGA), Scanning Electron Microscopy (SEM), and X-ray Diffraction (XRD).





(a). Schematic diagram of CMC device (b). Physical map

Admixture	C-0	C-0.5	CR-0.5	CR-1	CR-2
Carbon dioxide (%)	0	0.5	0.5	1	2
CL (%)	0	0	0.25	0.25	0.25

Cementitious materials(%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2
Cement	18.7	6.05	3.03	51.1	1.03	2.81	-
Fly ash	37.1	26.7	3.86	4.80	-	-	1.34
Mineral powder	29.6	14.9	-	33.4	9.05	1.97	-

Result & Discussion

Flowability

Impact of CO2: 0.5% CO2 reduced slump from 160 mm to 50 mm due to rapid setting.
Addition of CL: 0.25% CL restored slump to 130 mm, enhancing workability.

Compressive Strength

Reduction with CO2: CO2 reduced early and later-stage compressive strength.
Improvement with CL: CR-0.5 group with 0.25% CL showed strength increases at various ages.

- Figure 4: Compressive strength of specimens

Microstructure

Pore Structure: CO2 increased porosity, but CL addition reduced it.

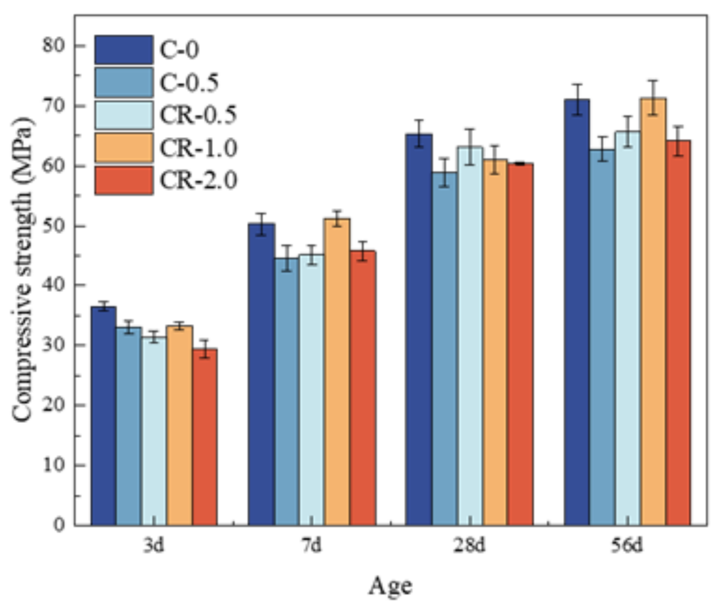
- Figure 5: Pore structure distribution of specimens at 7 days

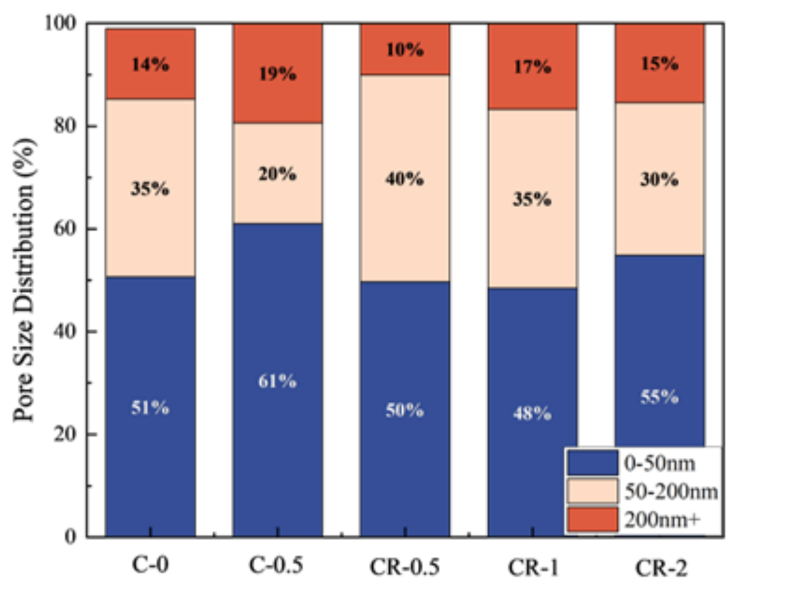
Thermogravimetric Analysis: Higher hydration product peaks in CO2-mixed concrete.

- Figure 6: Derivative thermogravimetric curve (DTG) and thermogravimetric (TG) curves of specimens at 7 days

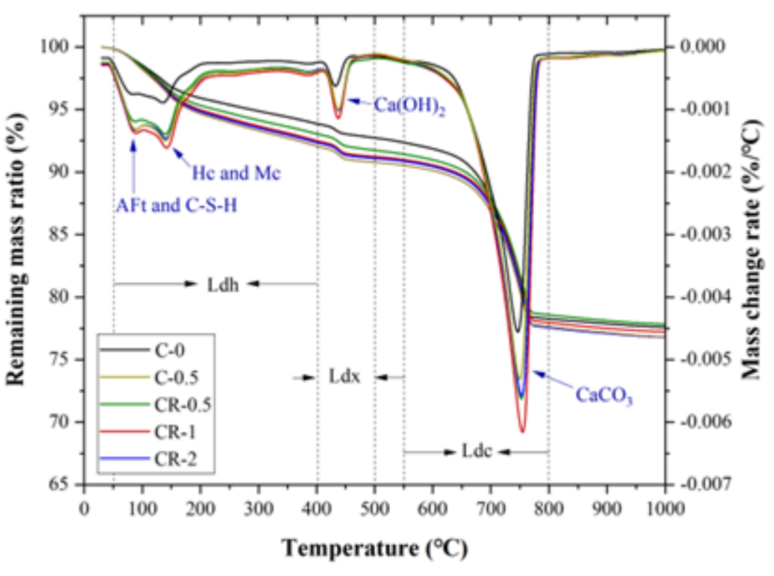
XRD Analysis: Increased calcite peak height with CO2 addition.

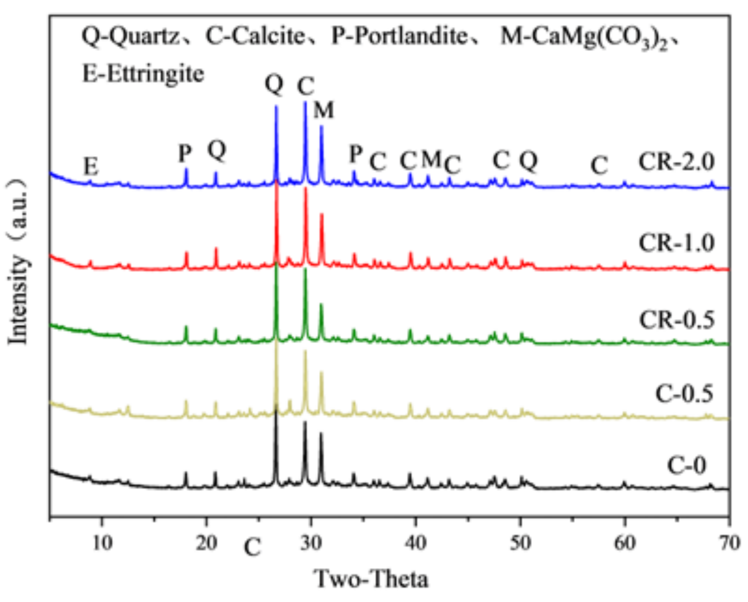
- Figure 8: XRD patterns of the specimens





Pore structure distribution of specimens at 7 days





Conclusion

This study demonstrates that incorporating a retarder (calcium lignosulfonate) into carbon-mixed concrete can effectively mitigate the adverse effects of CO2 on workability and mechanical properties. The synergistic use of CO2 and retarders enhances the technical performance and carbon sequestration efficiency of CMC. This approach offers significant potential for sustainable development in the concrete industry.

Reference

1. R.M. Andrew, Global CO2 emissions from cement production, 1928–2018, Earth System Science Data 11 (2019) 1675–1710. https://doi.org/10.5194/essd-11-1675-2019.
2. J.G. Jang, H.K. Lee, Microstructural densification and CO2 uptake promoted by the carbonation curing of belite-rich Portland cement, Cement and Concrete Research 82 (2016) 50–57. https://doi.org/10.1016/j.cemconres.2016.01.001.
3. Y. Mao, S. Drissi, P. He, X. Hu, J. Zhang, C. Shi, Quantifying the effects of wet carbonated recycled cement paste powder on the properties of cement paste, Cement and Concrete Research 175 (2024) 107381. https://doi.org/10.1016/j.cemconres.2023.107381.
4. S. Monkman, Y. Sargam, L. Raki, Comparing the effects of in-situ nano-calcite development and ex-situ nano-calcite addition on cement hydration, Construction and Building Materials 321 (2022) 126369. https://doi.org/10.1016/j.conbuildmat.2022.126369.
5. L. Liu, Y. Ji, F. Gao, L. Zhang, Z. Zhang, X. Liu, Study on high-efficiency CO2 absorption by fresh cement paste, Construction and Building Materials 270 (2021) 121364. https://doi.org/10.1016/j.conbuildmat.2020.121364.