

Genomic and Functional Characterization of a High-Performance MICP Strain for Sustainable Concrete Applications

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INTRODUCTION & AIM

Concrete is one of the most consumed materials globally, yet its production and maintenance contribute significantly to CO₂ emissions. Microbially induced calcium carbonate precipitation (MICP) offers a sustainable solution by enabling crack healing and CO₂ sequestration. This study aimed to isolate and characterize high-performance MICP-capable bacteria from waste concrete, focusing on their urease activity, sporulation efficiency, and genomic traits responsible for biomineralization. The goal was to identify a strain capable of surviving alkaline environments and enhancing the self-healing and durability of concrete.

METHOD

Microorganisms were isolated from crushed waste concrete through serial dilution and plating on urea-supplemented media. Forty-two isolates were purified, and eleven representative strains were selected based on morphological and biochemical diversity. Urease activity was quantified using Christensen's urea agar and colorimetric assays, while biomineralization efficiency was assessed in CaCl₂–Na₂CO₃ systems. Spore formation was induced using DSM medium and verified microscopically. Whole-genome sequencing (PacBio platform) was performed to identify genes associated with urease metabolism, pH homeostasis, and stress tolerance.

RESULTS & DISCUSSION

Among the tested isolates, one strain exhibited superior urease activity and CaCO₃ precipitation ability. FE-SEM and EDS analyses confirmed the formation of dense calcite crystals with high Ca content. Genomic analysis revealed a complete urease operon (*ureA–ureC*, *ureD–ureG*) responsible for efficient urea hydrolysis, as well as genes such as *nhaC* (Na⁺/H⁺ antiporter) and *mgtE* (Mg²⁺ transporter) facilitating adaptation to alkaline environments. These genetic features collectively enhance microbial resilience and mineralization efficiency, supporting its potential application in concrete self-healing and CO₂ mitigation technologies.

Urease Activity Analysis

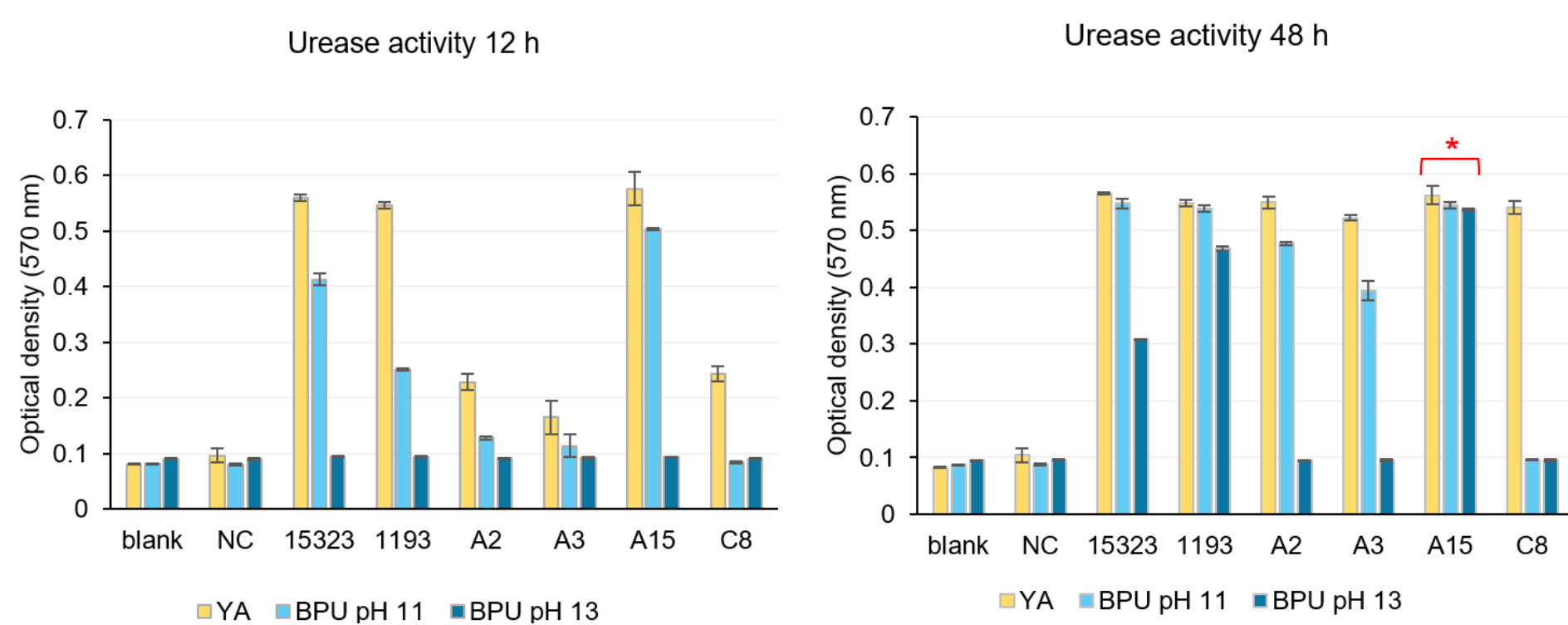


Figure 1. Urease activity of isolates under different pH conditions. (A) Urease activity after 12 h and (B) 48 h incubation in YA and BPU media at pH 11 and 13.

Calcium Carbonate Precipitation Capacity

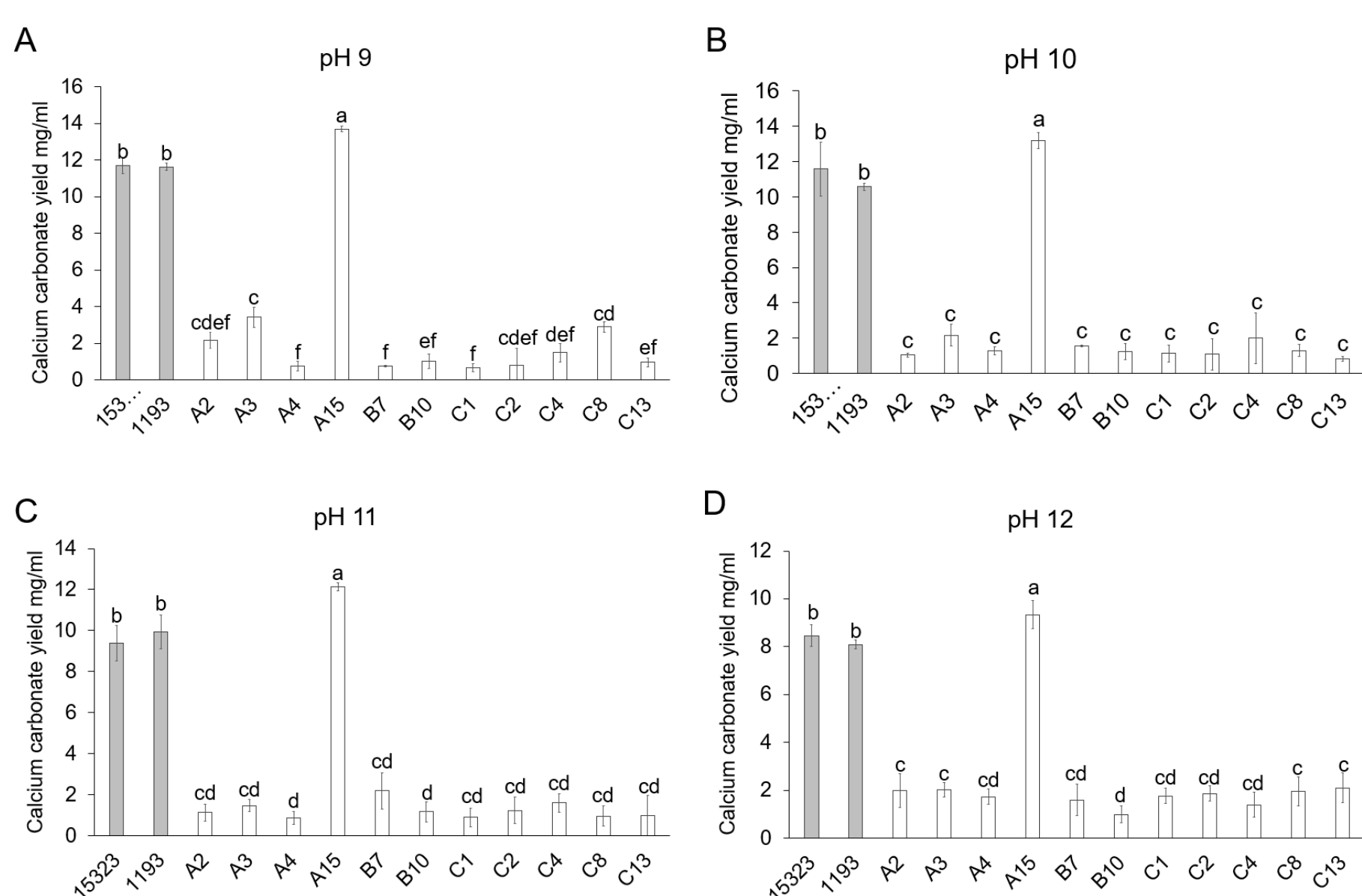


Figure 2. Calcium carbonate precipitation efficiency of isolates at various pH levels. (A–D) Quantification of CaCO₃ yield at pH 9–12 after 48 h incubation in BPU media.

CONCLUSION

- This study identified a highly efficient MICP strain exhibiting strong ureolytic activity and abundant CaCO₃ precipitation.
- The strain's sporulation capacity and stress-tolerance genes enable excellent survival in harsh concrete environments.
- These findings highlight its potential as a robust biological agent for sustainable and self-healing concrete applications.

Endospore Formation Efficiency

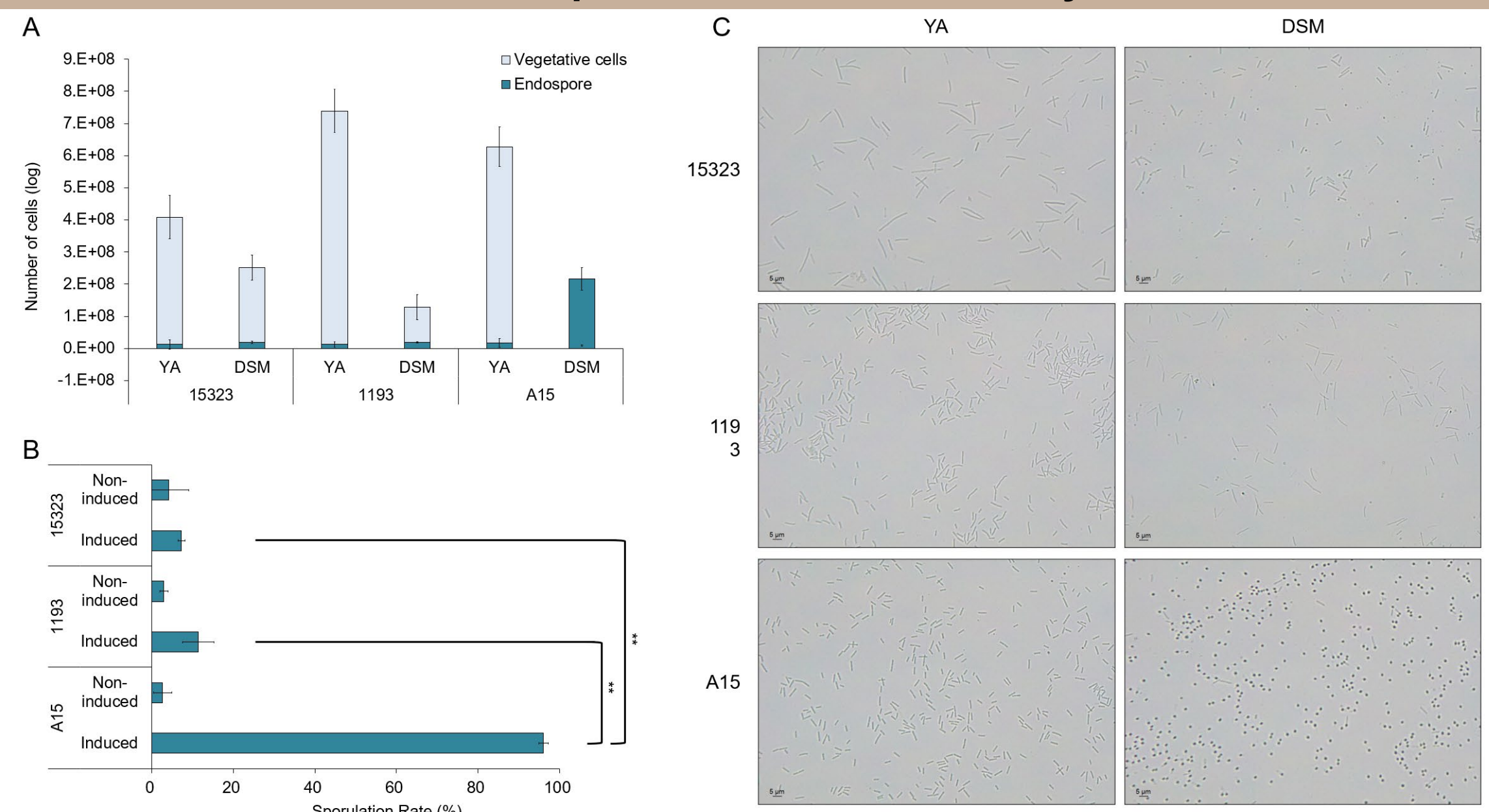


Figure 3. Sporulation efficiency and cell morphology of selected strains. (A) Total cell and endospore counts under YA and DSM conditions. (B) Comparison of sporulation rates before and after induction. (C) Microscopic images show abundant refractive endospores in DSM medium for strain A15, in contrast to vegetative cells in YA medium.

Identification of Target Gene Information

Table 1. Gene associated with sporulation and cell wall modification.

Description	Product	GO	InterPro	EggNOG
Sporulation	Cell wall hydrolase CwlJ	GO:0016787	IPR042047	COG3773
	SpoIVB peptidase	-	IPR008763	COG0750
	Cell wall hydrolase CwlJ	GO:0016787	IPR042047	COG3773

Table 2. Gene related to calcium carbonate precipitation.

Description	Product	GO	InterPro	EggNOG
Calcite precipitation	Urease accessory protein UreG	GO:0003924	-	COG0378
	Urease accessory protein UreF	GO:0006807	IPR038277	COG0830
	Urease accessory protein UreE	GO:0005737	IPR007864	COG2371
	Calcium-transporting ATPase 1	GO:0000166	IPR004014	COG0474

Table 3. Gene contributing to alkaline and oxidative stress resistance.

Description	Product	GO	InterPro	EggNOG
Alkaline resistance	Na ⁺ /H ⁺ antiporter NhaC	GO:0015297	IPR018461	COG1757
	Magnesium transporter MgtE	GO:0006812	IPR006667	COG2239
	Superoxide dismutase [Mn] 1	GO:0004784	IPR019831	COG0605
	Ferric uptake regulation protein	GO:0003700	IPR036388	COG0735

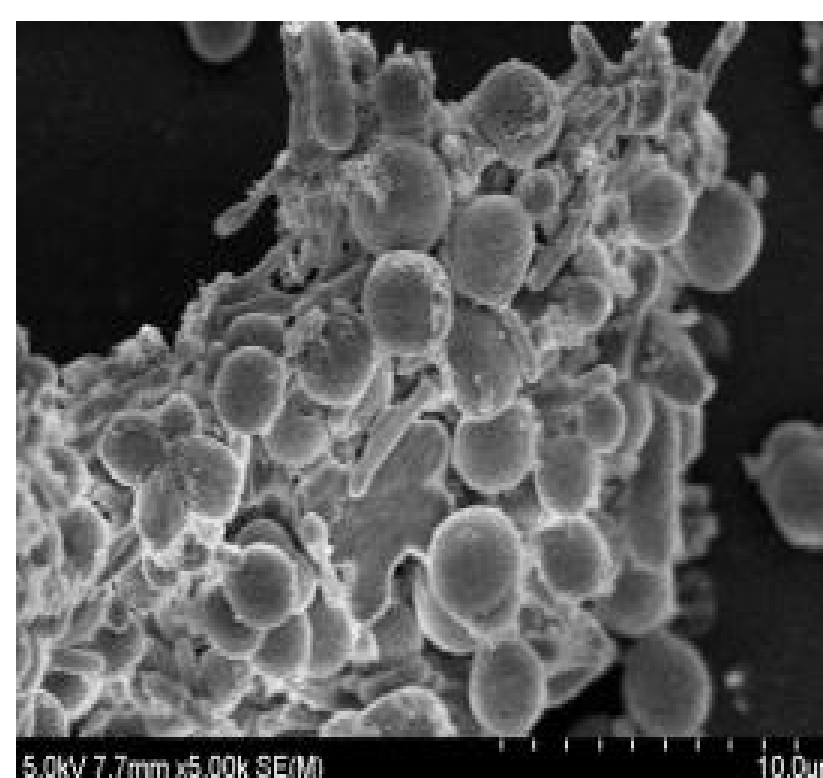


Figure 4. FE-SEM image of CaCO₃ precipitates produced by strain A15.

FUTURE WORK / REFERENCES

- Future research will focus on optimizing the incorporation of the strain into lightweight aggregates and mortar systems.
- Field-scale experiments will be conducted to evaluate self-healing efficiency and long-term CO₂ sequestration performance.
- Genetic and metabolic engineering approaches will further enhance urease regulation and cell viability under alkaline conditions.