Self Healing Concrete by Using Bacteria

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Introduction

Concrete is the second most used substance in the world, second only to water (Gagg 2014). Concrete is crucial to modern building and architecture and has been used since the times of the ancient Romans. Unfortunately, concrete does not last forever and can crack and break down. Since it is so ubiquitous, the problem of how to fix or repair concrete is well studied. Traditionally, repairing concrete is possible but has some drawbacks. Self healing concrete can help prevent the degradation that is the cause of most concrete damage. Self healing concrete comes in a variety of forms from chemical to biological (Amran et al 2022).

One promising method is to make concrete that can self heal by adding certain strains of bacteria. Certain species of bacteria produce carbonate which, when combined with calcium ions, make calcium carbonate, a main component of concrete. Several factors can affect how much $CaCO_3$ bacteria can produce.

In order to produce $CaCO_3$, bacteria need 3 ingredients. Urea is required for the urease enzyme, present in some bacteria, to convert into CO_3^{2-} . A source of calcium is needed to combine with the CO_3^{2-} to form $CaCO_3$. Finally, a source of nutrients is required to keep the bacteria alive and provide energy.

We used five different strains of bacteria as follows:

ATCC	Species name
14574	Bacillus badius
7055	Lysinibacillus fusiformis
11778	Bacillus cereus
4525	Lysinibacillus sphaericus
19606	Acinetobacter baumannii

Methods

We attempted to find the best conditions to produce the most $CaCO_3$. To do this, we varied concentrations of the three main components: urea, calcium salt, and nutrient broth. To analyze the bacteria, we used optical density (OD) and the scanning electron microscope (SEM).

Optical density
Optical density is the main method we used to determine $CaCO_3$ yields. The OD is the amount of light that passes through a sample. By comparing the initial OD to the OD after incubating, we can estimate the $CaCO_3$ produced.

Scanning electron microscope
The SEM is a microscope that can provide imaging at the nanometer scale. This is done by firing a beam of electrons at a sample and measuring the interactions to make an image on a smaller scale than a visible light microscope. While the SEM does not provide data on the amount of $CaCO_3$ that is formed, it does provide insight into differences in the product between strains and treatments.

Results

We started with a base recipe of 3 g/L urea, 20 g/L calcium acetate, and 13 g/L nutrient broth. This base was adjusted for each trial based on which aspect was being tested.

The first trial looked at the effects of nutrient broth concentration.

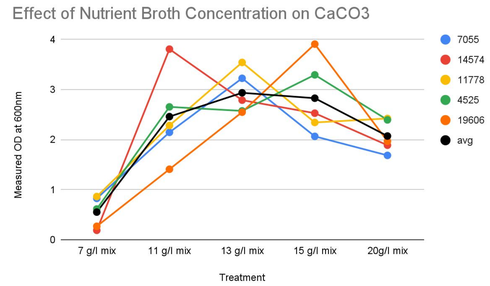

Figure 1 Nutrient broth concentration graph with average across strains

The second and third trials looked at urea concentrations.

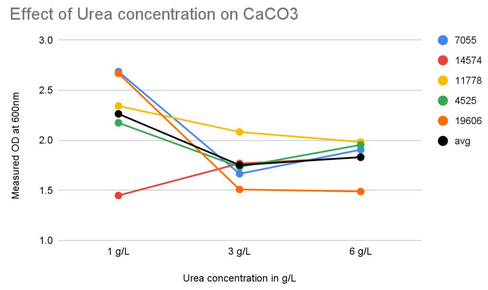

Figure 2 Urea concentration graph with average across strains

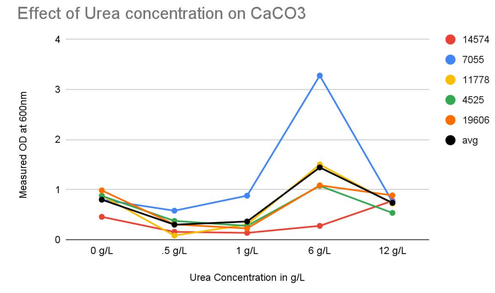

Figure 3 Urea concentration graph with average across strains

The SEM was used to look at different strains with 0.6 g/L urea treatment and no urea treatment.

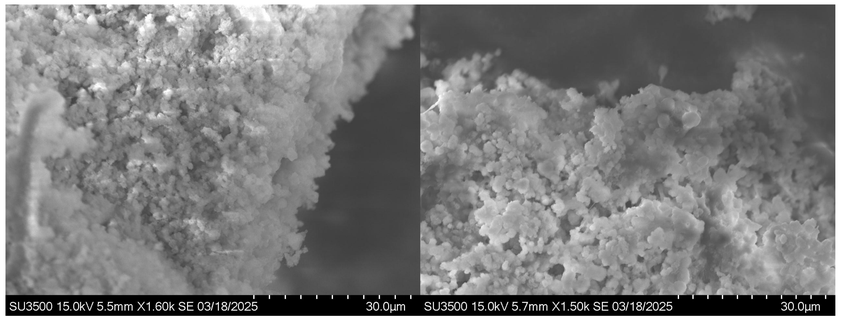

Figure 4 SEM images of strain 7055, left is 6 g/L urea right is no urea

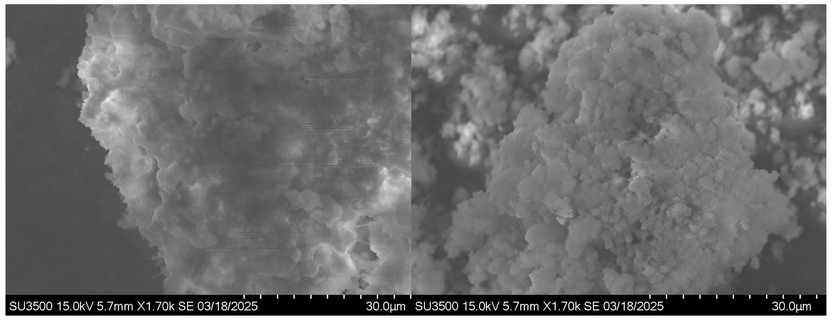

Figure 5 SEM images of strain 19606, left is 6 g/L urea right is no urea

Discussion

The nutrient broth trial showed results that were not particularly surprising. The broth we used suggests a concentration of 13 g/L and, for the most part, that is the concentration that showed the best results. We believe that the higher concentrations had issues with being over saturated between the high concentrations of broth and both urea and calcium salt.

The two urea trials produced interesting results. The trial in Figure 2 showed stronger results at lower urea concentrations. We suspected this could be due to higher concentrations of urea being toxic as discussed in Rahmaninezhad et al 2024. We ran a second trial with a wider range of urea concentrations in order to confirm and came out with different results as seen in Figure 3. It showed two points of interest: an effective concentration at 6 g/L and a surprisingly high optical density at 0 g/L. Almost all the urea concentrations from the third trial had optical densities less than the samples from the second trial. This discrepancy will be looked into as the project continues. As for the high apparent calcium carbonate concentrations at 0 g/L of urea, one explanation is that the OD can not distinguish between $CaCO_3$ and bacteria so it is possible that the bacteria grew more in the absence of urea and shifted the OD.

The SEM produced interesting images, however, it is difficult to form any conclusions at this point.

Future Directions

Before the end of this study, we will look more closely at both the urea concentrations and the differences in the SEM images.

One limiting factor of this study is the access to effective equipment. SNHU is already working on setting up a fluorescent microscope that will allow for additional analysis but it was not available in time for this study.

Future studies may wish to look into the effect of calcium salt concentrations as we did not get a chance to look at. There are also other factors that could affect bacterial yields like temperature and acidity.

Finally we did not have the time to test any of our conclusions in a practical concrete trial which would be an important next step in this research.

Special Thanks

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References

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