

Green Visionary Scholarship

By Michael Boland

As we gaze upon the timeless grandeur of ancient wonders such as the Great Wall of China or the Roman Pantheon, we notice their carefully chiseled stones and ornate splendor. However, we rarely consider the substance that supports those stones- concrete. For thousands of years, humans have sought to create the perfect blend of concrete.¹ Early civilizations experimented with different amounts of water, stone, sand and even volcanic ash. Concrete has become a fundamentally integral part of our lives. Homes, fortresses, palaces, bridges and more have relied on its strength and resilience throughout the millennia. After water, concrete is the second most used substance on Earth with over 10 billion tons produced each year.¹ Concrete acts as both the literal and metaphoric foundation of our lives. Yet, in spite of technological advances, concrete still remains prone to severe cracking.² As cracks accumulate over time, structural integrity is drastically reduced.² Monitoring cracks and carrying out repairs is expensive and time-consuming.^{2,3} This is not to mention that the manufacturing of concrete places a tremendous strain on our global environment.^{1,3} If concrete manufacturers were a country, they would be the third largest producer of carbon dioxide in the world.¹ Bioconcrete is a revolutionary development that will change the way we build everything as it produces more durable structures and is significantly healthier for our planet.

The concrete that we use today is composed of two main parts.⁴ The aggregate, a mixture of fine and course stone, and cement, the bonding agent that holds the various components together.⁴ Water is mixed with the cement to create a cement paste.⁴ The aggregate is then added.⁴ Since concrete is somewhat fluid when poured, it can be formed into specific shapes

using molds.⁴ Through the process of hydration, the cement cures over time, becoming solid.⁴ To increase the durability and strength of concrete, it is often poured on top of steel supports called rebar.² This reinforced concrete is extremely sturdy and allows for exceptionally durable structures to be built.² The thick coating of concrete over the steel also acts to protect the steel from water and atmospheric gases which could result in rust, ultimately decreasing structural integrity.^{2,3}

While reinforced concrete has allowed us to build bridges that extend for miles and create skyscrapers that soar to greater and greater heights, after only twenty to thirty years the concrete begins to crack.² Concrete shrinkage, freezing and thawing, and the application of heavy loads all promote fractures to form.² Even small fractures can threaten the strength of structures.² Minute cracks can allow for water and oxygen to corrode steel rebar as well as facilitate larger cracks. The American Society of Civil Engineers estimates that it will cost over \$4.6 trillion to repair the United States' infrastructure.⁵ An estimated 70% of infrastructure is composed of concrete.³ Dams, bridges, roads, airports, to name just a few examples, will require concrete to carry out all of their improvements. With tremendous financial costs and risks to safety, scientists have been researching ways to improve the lifespan of concrete.²

Concrete can naturally heal itself in a process called autogenous healing.² In this process, water enters the cracks of the concrete and interacts with the calcium oxide.² The resulting compound, calcium hydroxide, then reacts with the carbon dioxide in the air.² This reaction forms calcium carbonate crystals which fill the crack.² However, these crystals are very limited in their capacity to heal fractures. Only cracks less than 0.3 mm wide can be filled by this process.² To increase the self-healing capacity of concrete, adhesive filled fibers and tubes can be added to the concrete mixture when it is still in its semiliquid state.² When the concrete splits, the

adhesive glue is freed, filling the crack with a paste-like glue.² The adhesive doubles concrete's natural healing capacity as it can fill cracks up to 0.6 mm wide.² However, the addition of adhesives has been found to change the properties of concrete, resulting in even more severe cracks over time.²

The most promising approach to create self-healing concrete is with the utilization of bioconcrete which has been given this name because of the microbes that help to preserve it.³ Researchers recognized that numerous bacteria can produce significant quantities of calcium carbonate crystals, similar to the ones produced in concrete's natural healing process. To harvest this natural phenomenon, scientist studied numerous strains of bacillus bacteria. Eventually, the perfect species was found. *Bacillus pseudofirmus* is resistant to severe drought, food shortages and harsh alkaline environments, making it the ideal candidate to live in concrete.³ Small, clay capsules that house the bacteria's spores are mixed into the concrete.^{3,6} These capsules, about two to four millimeters in size, prevent the bacteria from propagating during the concrete's original mixing and allows them to remain dormant, sequestered from air and water.^{3,6} In fact, if the capsules are not disturbed, the spores can remain dormant for hundreds of years. When the concrete inevitably cracks, the clay capsules filled with the spores break open.³ The spores, now exposed to air and water, begin to multiply.^{2,3} Feeding their growth is calcium lactate.³ The substance was chosen because unlike other possible food sources such as sugar, calcium lactate does not weaken concrete's strength.³ By exiting their dormant state and increasing their metabolic activity, the bacteria consume oxygen that might have resulted in the rusting of the steel rebar.² *Bacillus pseudofirmus* also produces a calcium carbonate shell.^{2,3,6,7} Calcium carbonate is limestone, a relatively durable building material. As these bacteria multiply in numbers, their strong shells fill the cracks that ran through the concrete. In a matter of three

weeks, they can completely fill a gap that is 1 millimeter in size.² When the bacteria seal the crack, they effectively prevent themselves from receiving air or water which would continue to stimulate their growth.^{2,3,6} Once sealed off from the atmosphere, they then produce spores that can withstand years of drought and limited food.^{2,3} This crucial step prepares the concrete for another fracture as spores are made ready to fill a crack should one appear.²

The benefits of using bioconcrete are astounding. Its use is expected to significantly decrease the maintenance costs of bridges, roads, retaining walls and tunnels, which currently cost the United States tens of billions of dollars.³ Bioconcrete would also help to reduce the harmful effects of standard concrete on the environment. The concrete we use today is responsible for roughly 8 percent of the world's carbon dioxide output with over 2.2 billion tons of the greenhouse gas emitted each year.^{1,4} The mounting demand for concrete has also raised concerns over the dwindling supply of natural resources necessary for its production.¹ Concrete also uses about ten percent of Earth's fresh water.¹ Approximately 75 percent of this water is used in regions that are classified as "water-stressed" or in "drought."¹ As we continue to learn more about concrete's harmful effects, we have come to realize that decreasing its production would have numerous benefits on a global scale. Since bioconcrete has the ability to heal itself, it lasts longer and requires fewer repairs.^{2,3,6} This would help to reduce the amount of concrete that is produced each year simply to maintain the structures that stand today. Although cost is one of the largest impediments to bioconcrete's widespread use, researchers have found ways to reduce the price to make it more competitive with traditional concrete.³ Despite bioconcrete being more expensive, the costs of standard concrete extend well beyond its price tag alone. The massive contributions to climate change, water scarcity and resource depletion are problems that are

extremely costly and tremendously complex to solve. After accounting for these destructive consequences, bioconcrete may ultimately prove to be less expensive.

The English word “concrete” derives from the Latin “con” and “crescere” which means “to grow together.”⁸ After all, concrete has made it possible to build cities with roads, schools, hospitals and industry. It simultaneously provides the foundation at our feet and shelters us from the elements above. We have used concrete to beautify our world and erect structures that symbolize humanity’s triumph throughout the centuries. As concrete continues to remain essential, bioconcrete unlocks new possibilities to produce a healthier, greener world for all.

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A handwritten signature in black ink that reads "Michael Boland". The script is cursive and fluid, with the first letters of each word being capitalized and prominent.

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References:

1. Watts J. Concrete the most destructive material on Earth. The Guardian website.
<https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth>. Published February 25, 2019. Accessed May 27, 2020.
2. Jin C. What is the cracks in concrete could fix themselves. YouTube.
<https://www.youtube.com/watch?v=znSeL66e8qE>. Published October 16, 2018.
Accessed May 27, 2020.
3. Giatec Scientific Inc. Self-Healing Bio-Concrete. Giatec Scientific website.
<https://www.giatecscientific.com/education/bio-concrete/>. Published May 14, 2015.
Accessed May 27, 2020.
4. Rodgers L. Climate Change The massive CO2 emitter you may not know about. British Broadcasting Company website. <https://www.bbc.com/news/science-environment-46455844>. Published December 17, 2018. Accessed May 27, 2020.
5. Frank T. Civil engineers say fixing infrastructure will take \$4.6 trillion. Cable News Network website. <https://money.cnn.com/2017/03/09/news/infrastructure-report-card/index.html>. Published March 9, 2017. Accessed May 27, 2020.
6. Stewart A. The 'living concrete' that can heal itself. Cable News Network website.
<https://www.cnn.com/2015/05/14/tech/bioconcrete-delft-jonkers/index.html>. Updated March 7, 2016. Accessed May 27, 2020.
7. Structural Engineer. Using bacteria to make a self-healing cement. International Information Center for Structural Engineers website.
<https://www.thestructuralengineer.info/news/using-bacteria-to-make-self-healing-cement>.
Published May 12, 2017. Accessed May 27, 2020.

8. Online Etymology Dictionary. Online Etymology website.

<https://www.etymonline.com/word/concrete>. Accessed May 27, 2020.