SELF-HEALING CONCRETE: BIO-MINERALIZATION

I. THE PROBLEM

There are two guarantees when it comes to concrete. Number one, concrete will “harden” – gain strength. Number two, concrete will crack. Cracking is inevitable and is typically the most common complaint in the concrete industry. Engineers reinforce concrete with embedded rebar to give the beam or column strength in the event they crack (Miller). Specifically, rebar in concrete carry tensile loads, so it has the purpose to reduce crack formation (Tittelboom). Reinforcement snaps the face of cracks back together once created (Miller). Some problems regarding the development of cracks are as follows ("Self-Healing..."):

1. Cracks endanger the durability of rebar and concrete. Since cracks expose the reinforcement, water has the ability to find its way through and corrode the rebar. This could cause collapse of a structure if severe enough.
2. Crack repair is challenging when cracks are not visible or accessible.
3. Crack repair can be costly due to materials, traffic shutdowns, and mobilization.
4. Cracks are of major concern to owners and the general public, because they are not aesthetically pleasing, and generally clients are not educated on types of cracks and when they should be of concern (Miller).

To combat the never ending war with cracks Henk Jonkers, of Delft University of Technology, invented a way to give concrete a longer life by introducing the construction industry to bio-concrete. Jonkers is a microbiologist that started his research in 2006 when asked if self-healing concrete was possible. His self-healing concrete produces limestone to seal surface cracks [See Figure 1] (Stewart). This concept is called bio-mineralization, and is pollution free (Vekariya).

II. THE BACTERIA

The bacteria to be chosen for the self-healing concrete needed to have the ability to survive the harsh environment of the concrete (Stewart). Concrete has a very high pH value, so a only an alkaliphilic bacteria could be chosen for the job ("Self-healing..."); hence, bacillus pasteurii was elected due to its ability to thrive in alkaline conditions, produce spores that survive without food or oxygen, and its harmless nature to the environment and humans (Ravindranatha). Moreover, bacillus bacteria can stay dormant for years before being activated by water (Stewart).
The next challenge was to find bacteria that could create a repair material to fill cracks in concrete. Fortunately, bacillus pasteurii has the behavior to make this happen. In order for bacillus pasteurii to create limestone, reach crystallization, it needs food. Initially, sugar was an option; however, sugar makes concrete weak and it retards the curing of concrete. So, the food chosen was calcium lactate [See Figure 2]. Bacillus pasteurii and calcium lactate are put into biodegradable capsules and mixed with clay pellets before added into the concrete mixture. The clay pellets ensure that water does not activate the bacteria (Vekariya). In fact, “the bacteria combination can lie dormant for up to 200 years when not exposed to water” (Vekariya).

When water enters the cracks in the concrete, the capsules dissolve releasing the bacteria and food (Stewart). With the presence of water, the bacteria germinate to form calcium carbonate, an inorganic crystal that can withstand almost all temperature conditions, also known as limestone (Ravindranatha). This resulting crystallization is stronger than the concrete itself (Stewart). The calcium carbonate secretion fills pores within the concrete creating a more compact member that is more resistive to seepage [See Figure 4]. This action can be compared to a fractured bone healing itself (Vekariya). “As the texture becomes more compact, the compressive strength is considerably increased. Thus, this process can reduce the seepage considerably permanently” (Ravindranatha).
Oxygen is essential in the healing process, because oxygen causes the corrosion of rebar. So, when the self-healing concrete cracks, the bacterium uses all of the oxygen to produce the limestone; in turn, this increasing the durability of the reinforced concrete structure. In typical laboratory experiments, it takes approximately seven days for the bacteria to germinate and seal the crack. However, the amount of time for the bacteria to secrete calcium carbonate and fill the void in the concrete depends on the width and depth of the crack (Vekariya).

III. PRACTICAL APPLICATIONS

There are two main goals when designing a concrete structure. One, to create a structure that is safe. Meaning it meets code, safety factors, and withstands loads and natural disasters. If a building is to collapse, it must be at a point where everyone in or on that structure can tell it is unsafe and has time to evacuate before it topples down. Two, design a structure in an economical manner (Miller). Therefore, the durability of concrete is of utmost importance, because lives are at stake.

The issue with concrete is that it is porous. Water will find a way into a concrete structure, even on a microscopic scale. Over time this causes cracks, reducing the structural integrity of the concrete members. An additive that seals pores and cracks would reduce the permeability of concrete and improve the longevity of its life. Conventionally, sealing agents are used such as latex emulsions, epoxies, and other surface treatments that include “water repellents such as silanes or siloxanes” (Ravindranatha). However, these methods suffer from limitations including susceptibility to ultraviolet radiations, unstable molecular structure, high costs, incompatible interfaces, and difficulty of application (Ravindranatha).

Hence, the most valuable outcome of self-healing concrete is its ability to enhance the strength of concrete by keeping water from deteriorating the structure. Several other practical uses of self-healing concrete include (Vekariya):

- Constructing underground retainers for hazardous waste ("Self-healing..."
- Repairing limestone monuments
- Erosion prevention of loose sand
- Better resistance towards freeze-thaw action
- Reduction in the permeability of concrete
- Reduction in the corrosion of rebar
- Sealing cracks in concrete structures [See Figure 4]
Not only is bacillus pasteurii environmentally friendly and harmless to humans, but putting forth the extra upfront cost will result in low maintenance costs as time passes and longer life span of a structure (Vekariya).

Of course with every new technology that surfaces, there are its drawbacks. Unfortunately, the cost of the bacterial concrete is easily double in price. The research of calcite precipitation is expensive. Additionally, the growth of the bacteria is not good in any atmosphere. Although bacillus pasteurii was chosen due to its ability to withstand harsh weather conditions, it cannot survive all environments. Lastly, there is no code for bio-concrete (Vekariya). Code serves as a basis for checks and balances of material performance. In other words it enforces quality and serviceability (Miller). Code is a must for any design of a structure.

**IV. CONCLUSION**

Jonkers, the inventor of self-healing concrete [See Figure 5], hopes that his concrete will be the start of a biological buildings era. In fact, “It is combining nature with construction materials,” he says. “Nature is supplying us a lot of functionality for free – in this case, limestone-producing bacteria” (Stewart).

This new concept of combining nature and built structures is where society is heading. With LEED and “going green”, the public is more concerned now with the environment than ever. Self-healing concrete is not only practical in the concept of increasing the durability and longevity of concrete, but it is also environmentally friendly. No longer will engineers have to worry about maintenance of concrete cracks and fissures. Self-healing concrete appears to be on the brink of implementation in the construction industry.
WORKS CITED

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