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Review of Bacteria-Based Self-Healing Concrete

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Abstract: *Concrete is one of the most widely used construction materials and has a high tendency to form cracks. These cracks lead to significant reduction in concrete service life and high replacement costs. Although it is not possible to prevent crack formation, various types of techniques are in place to heal the cracks. It has been shown that some of the current concrete treatment methods such as the application of chemicals and polymers are a source of health and environ-mental risks, and more importantly, they are effective only in the short term. Thus, treatment methods that are environmentally friendly and long-lasting are in high demand. A microbial self-healing approach is distinguished by its potential for long-lasting, rapid and active crack repair, while also being environmentally friendly. Furthermore, the microbial self-healing approach prevails the other treatment techniques due to the efficient bonding capacity and compatibility with concrete compositions. This study provides an overview of the microbial approaches to produce calcium carbonate (CaCO3).Prospective challenges in microbial crack treatment are discussed, and recommendations are also given for areas of future research.*

I. INTRODUCTION

Despite concrete's advantages, it has a high tendency to form cracks allowing aggressive chemicals to penetrate into the structure. Cracks are one of the main causes of concrete deterioration and decrease in durability. Cracks can be formed in both plastic and hardened states. Formwork movement, plastic settlement and plastic shrinkage due to rapid loss of water from the concrete surface result in crack formation during the plastic state, whereas weathering, drying shrinkage, the thermal stress, error in design and detailing, chemical reaction, constant overload and external load contribute to crack formation in hardened state Moreover, concrete structures suffer from relatively low tensile strength and ductility. To address low tensile strength and ductility, concrete is usually reinforced with embedded steel bars. Reinforcement bars have positive effect on crack width restriction by controlling plastic shrink-age; however, they cannot prevent crack formation Bio-concrete is proving to become a game-changer in the world of construction. By having the material essentially "heal itself" from cracks and breakage, builders will have an easier time completing projects and handling costly repairs. Bio-concrete will also play a critical role in structural integrity and durability by reducing the risk of a building collapsing.

As the most commonly used material in construction, concrete has been relied on for decades to provide durability, strength, and flexibility. Significant advancements have been made in the world of concrete manufacturing and usage over the years. Builders can now access concrete in multiple grades, compositions, and performance levels. But In 2017, a Dutch researcher (Hendrick Jonkers) developed one of the most innovative features that concrete could have. By slightly tweaking the composition of regular concrete, he infused a biological ingredient that made concrete have self-healing properties.

Bio-Concrete can help Construction Companies

Research surrounding self-healing concrete surfaced in 2015, sparking interest in builders, estimators, engineers, and other stakeholders as to how bio-concrete could be utilized to streamline daily construction activities. Does bio-concrete have the potential to become the future of construction? The numerous benefits of this material make it a front-runner for widespread adoption in years to come.

Bio-Concrete is useful and Applicable to Construction Companies in the following ways.

Sealing Small Cracks that could Eventually become Larger

Perhaps one of the most powerful applications of bio-concrete is that it can be used to seal up small cracks within larger slabs of concrete. It is these small cracks that eventually expand to cause significant damage in buildings, bridges, and other infrastructure. Bio-concrete can seal cracks of up to 0.8mm in width, catching the problem in advance and preventing significant structural damage.

Applicable to Different Types of Infrastructure

Bio-concrete is also usable in many different contexts. The flexibility of bacillus bacteria makes it functional for bridges, buildings, tunnels, and other types of infrastructure. The wider use functions of this material can open up many new possibilities in engineering, microbiology, and construction. Not only can you save on costs during your future projects, but you can also explore new designs, enjoy more durable structures, and cut costs down the road.

An Environmentally Friendly Solution

The benefits of bio-concrete extend beyond economic applications. This material also reduces carbon emissions, making it possible for commercial and residential builders to lower their carbon footprints. By using less concrete to carry out maintenance and repairs, there will be fewer carbon emissions into the environment over time. Sustainable construction is the future of our industry and bio-concrete is at the forefront of promoting this revolution.

Active for Long Periods

Endurance tests were recently carried out on bio-concrete to assess its durability and strength. Results show that the material is expected to last for over 200 years within its proper composition. This also means that clay pellets in the biochemical mixture are durable even under multiple weather and physical conditions.The durability of bio-concrete is a game-changer that makes this material applicable in many different contexts.

Hendrick Jonkers, the Dutch researcher who produced bio-concrete, is also working on a new techniquefor encapsulating bacillus bacteria into concrete mixtures.

This will further reduce production costs and increase the use-value of this revolutionary material. The future of bio-concrete and sustainable construction is bright, and your business shouldn't be left behind in benefitting from this innovative building option.

The construction industry isn't slowing down. Keep up with the digital transformation by trialling Cubit, an innovative natural estimating software to help save you time and money on your projects today.

II. COMPRESSIVE AND FLEXURAL STRENGTH

The basic micro-mechanism of strength restoration and crack healing in bacterial concrete is the transformation of soluble organic nutrients into inorganic $CaCO_3$ crystals that seal the cracks [1, 2]. Recent studies have shown that the strength restoration of cracks through $CaCO_3$ follows a multi-factor-criteria approach that can be divided into physical and chemical characteristics. In chemical characteristics, the type and concentration of bacteria [2], pH of the medium, and nucleation site for immobilization of bacteria [3] are the most effective factors on the strength development. Fig. 11 presents the results of 65 studies and their reported compressive and flexural strengths based on bacterial dosage. Based on this figure, the highest compressive strength range was achieved in the bacteria dosage range between 105 to 108 cfu/ml.

In addition, the type of bacteria can also play a significant role in strength values. As was reported by Rauf et al. [2], Bacillus Sphaericus exhibited a higher strength regain compared to Bacillus Cohnii and Bacillus Subtilis due to the higher calcite precipitation of Bacillus Sphaericus. Chen et al. [1] and Rauf et al. [2] studied the immobilization of bacteria using ceramsite sand and natural fibers as carrier compounds to stimulate microbial induced calcite precipitation, respectively. In their analysis, it was found that proper immobilization techniques can increase the flexural strength of the bacterial concrete by 56–72%.

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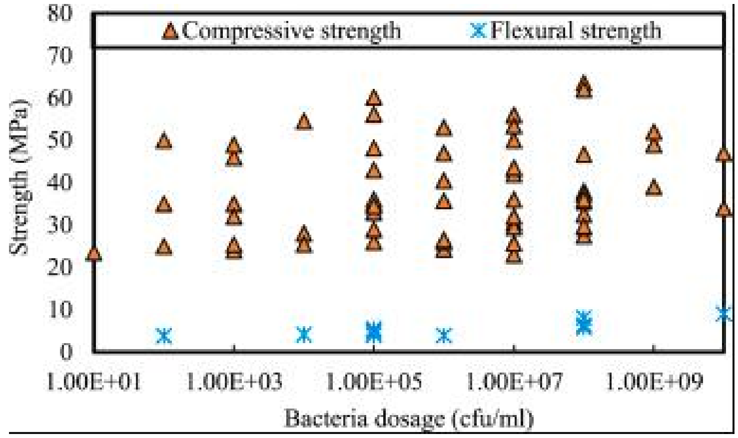
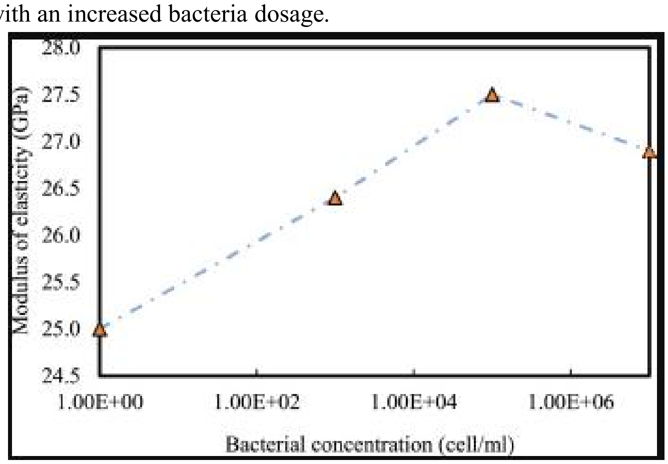
They also reported that natural fibers could further provide protection against the alkaline medium within the concrete mixture and increase the compressive strength by up to 42%. The strength increase can be attributed to the potential ability of carriers to protect and, at the same time, provide the already-included nutrients to bacteria to form CaCO3 for further sealing the pores and cracks [1,2].



III. MODULUS OF ELASTICITY

Modulus of elasticity refers to the concrete ability to deform within the elastic stress-strain region without fracturing the elasticity of the concrete material generally depends on the type and size distribution of the aggregate, duration and type of curing and reinforcement.In bacterial concrete, despite the relatively higher impact of these factors, the bacteria content is found to significantly affect the elastic modulus.

Figure shows the variation of 28-day elastic modulus of bacterial concrete containing Bacillus Sphaericus bacteria with various bacteria dosages. As can be seen in the figure, an increase in the bacteria dosage up to a certain level caused an increase in the elastic modulus, which can be due to the increased compaction at the ITZ of the microstructure with an increased bacteria dosage.



IV. CONCLUSIONS AND SUMMARY

The crack healing process of bacterial concrete depends on the availability of nutrition and survival of the bacteria. This process, although have been done in numerous studies, requires adaptation of certain techniques to preserve the living organisms which poses a great challenge for large scale application of self-healing bio-concrete.

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