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Research Article

Bio Cement – An Eco Friendly Construction Material

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Abstract

The invention of microorganisms involvement in carbonate precipitation, has paved the way to the exploration of this process in the field of construction engineering. Bio cement is a product innovation from developing bioprocess technology called bio cementation. Bio cement refers to CaCO3 deposit that is formed due to the microorganism activity in the systems which are rich in calcium ions. This paper overviews bio cement, bio concrete in general and the study also sheds light on benefits of bio cement over traditional agents and also the issues that lie in the path of successful commercialization of the technology of microbial induced calcium carbonate precipitation (bio cement) from lab(experiment) to field (commercial) scale.

Keywords*: bio cement, bio cementation, carbonates precipitation, bio concrete*

1. Introduction

Construction engineering consumes a large amount of materials from non-renewable resources, most of which contribute CO2 emission to the air at their production or application stage. Technology development related to the construction material and their production is necessary, in order to maintain the sustainability and to reduce the production of CO2 emission. Moreover, the buildings and traditional structures get deteriorated after a given time. Therefore self-healing is necessary to enhance the durability of building structures and the conservation of cultural heritage. The evidence of microorganism involvement in carbonate precipitation has lead to the development of bioprocess technology and its application in the self healing of construction material and thus has shown a solution to all the many a problem faced by them deterioration included.

The constant developments in the field of civil engineering and the growth of industrial activity have created a growing demand for materials for the construction industry that do more and more to comply with structural requirements and meet stricter demands for working conditions and environment. Traditionally, mechanical strength has been the main criterion used when choosing building materials such as cement, concrete or bricks. Compressive strength, permeability and corrosion analysis are the most common used measures in designing of buildings structures. Considerable effort has been devoted to developing high-strength materials. However, with increasing volumes of constructed facilities that needs to be maintained, the focus is shifting towards durability.

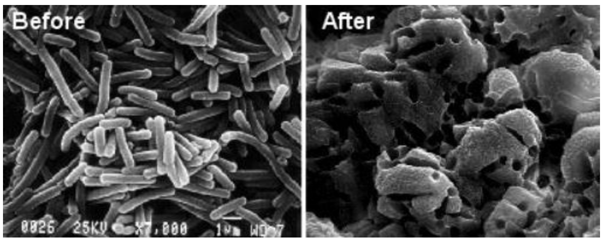

Figure -1 Carbonate precipitation activity of bacteria

The precipitation of calcium carbonate (CaCO3) may be performed by microorganism activity and it produces massive limestone or small crystal forms. These deposits of calcium carbonate are known as bio cement or microbial induced carbonate precipitation (MICP)

1.1 Bio cement and its many advantages

Bio cement has the following advantages

1. Bio cement needs a much shorter time for production and the in-situ process raw material of bio cement are produced at low temperature
2. More efficient compared to an ordinary cement which use temperature up to 1500°C in production process
3. Bio cement can be used as eco construction material since it consume less energy and less CO2 emission in the production process as compared to other ordinary cement.
4. It increases compressive strength of mortar by up to 38%.

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Figure – 2 Filling of crack space in Concrete
The space due to cracks is filled with calcite precipitate by microbes

5. Bio cement can remediate cracks in building materials and monumental stones and regain strength within 28 days.
6. To make the process economical, microbial additives can be prepared by growing cells using industrial by products such as lactose mother liquor and corn steep liquor as nutrient sources.
7. It enhances the durability of bricks by reducing their permeability and increasing compressive strength.
8. The reduced permeability rates resulting from the microbial additive will increase the concrete structures useful life.

2. Bio cementation

Bio cementation is a process to produce binding material (bio cement) based on microbial induced carbonate precipitation (MICP) mechanism. This process can be applied in many fields such as construction, petroleum, erosion control, and environment. Application in construction field include wall and building coating method, soil strengthening and stabilizing, and sand stabilizing in earthquake prone zone .
Primary role of microorganism in carbonate precipitation is mainly due to their ability to create an alkaline environment (high pH and DIC increase) through their various physiological activities. Three main groups of microorganism that can induce the carbonate precipitation are - (i) photosynthetic microorganism such as cyano-bacteria and microalgae; (ii) sulphate reducing bacteria; and (iii) some species of microorganism involved in nitrogen cycle. Photosynthetic microorganisms utilize urea using urease or urea amidolyase enzyme, based on which it is possible to use microalgae as media to produce bio cement through bio cementation.
In application, the precipitation of calcium carbonate (bio cement) is combined with other supporting material such as sand. The patented method of producing bio cement can be seen in fig 3. Bio cementation illustrated in figure 3 uses heterotroph bacteria Bacillus pasteurii with urea hydrolysis mechanism. The cementation process occurs in pipe columns filled with commercial sand contained silica.

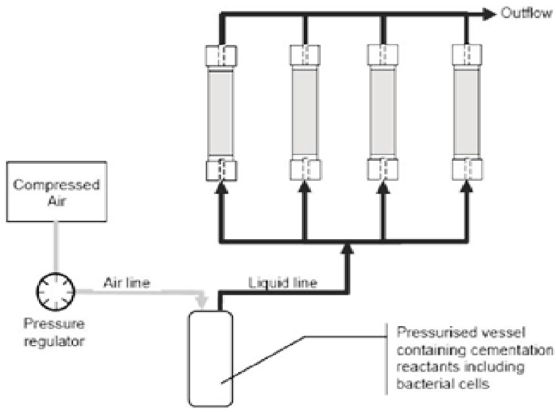

Figure- 3 Preparation process of bio cement

Urea/calcium solution and bacteria solution were mixed immediately and put in the pressurized vessel to be injected to the sand core in pipe column for several time until the sand core fully saturated. Bio cementation takes about 24 hours to complete the reaction, after that the bio cement were dried in temperature of 60˚C.

In general, mortar refers to ready to use binder material contained a binder, and sand or aggregate. Biological mortar consists of three main components such as limestone powder, nutrient and bacterial paste. Bio cementation applied in concrete rift remediation and the production of bacterial concrete has been investigated. Specimen of crack in concrete filled with bio cement shows the significant increment of strength and stiffness value compared with specimen without bio cement.

2.1 Bio concrete

It is a well-known fact that the cement industry is one of the most polluting ones with coal burning power plants. This is why many concerned scientists and engineers have been trying to come up with alternative cement-like materials, which cause as little harm to the environment as possible. Unfortunately, regardless of all the great efforts, we hardly ever hear of a successful story, the result from which can really be used outside the lab. The Structural Technology Group has developed and patented a type of biological concrete that supports the natural, accelerated growth of pigmented organisms. The material, which has been designed for the façades of buildings or other constructions in Mediterranean climates, offers environmental, thermal and aesthetic advantages over other similar construction solutions. The material improves thermal comfort in buildings and helps to reduce atmospheric CO2 levels. This is probably the reason why when two Dutch scientists from University of Delft- Eric Schlangen and Henk Jonkers, first presented their invention of an eco-friendly, bio-concrete, which can regenerate itself when cracks occur, many looked at the news very skeptically.

But, no negative responses could stay in the way of the two guys, who had one and only aim- to construct an entire building out of their miracle bio-material.

Figure-4 First ever complete bio-cement building

The scientists proudly present the first ever complete building (fig 4), which can repair itself and prevent structural degradation. The bio-cement that makes up the small lifeguard station, located on the coast of a small lake, consists of bacteria and calcium lactate. When a crack occurs, the bacteria, which can survive for years without food or oxygen, are activated with water. They begin to feed on the calcium lactate, and produce calcite, which is then, accumulated it in the space of the crack.

Henry jonkers, bacterial concrete extends the life of bridges, streets and tunnels and opens up completely new perspectives for concrete production," said EPO President Benoît Battistelli, announcing the European Inventor Award finalists. "This forward-looking innovation is a successful combination of microbiology and civil engineering - two sciences that are unlikely collaborators at first glance.

The positive side-effect of this property: the bacteria consume oxygen, which in turn prevents the *internal corrosion* of reinforced concrete. However, the bacteria do not pose a risk to human health, since they can only survive under the alkaline conditions inside the concrete.

Figure-5 The above is a picture of a construction made of bio concrete. It may be observed that the cracks are self-healed

Based on different findings, a team of researchers developed three different bacterial concrete mixtures: self-healing concrete, repair mortar, and a liquid repair system. In self-healing concrete, bacterial content is integrated during construction, while the repair mortar and liquid system only come into play when acute damage has occurred on concrete elements. Self-healing concrete is the most complex of the three variants. Bacterial spores are encapsulated within two- to four-millimetre wide clay pellets and added to the cement mix with separate nitrogen, phosphorous and a nutrient agent. This innovative approach ensures that bacteria can remain dormant in the concrete for up to 200 years. Contact with nutrients occurs only if water penetrates into a crack - and not while mixing cement.

This variant is well-suited for structures that are exposed to weathering, as well as points that are difficult to access for repair workers. Thus, the need for expensive and complex manual repairs is eliminated.

3. Eco Friendly Reduction of Co2

The new material, which has various applications, offers environmental, thermal and aesthetic advantages, according to the research team. From an environmental perspective, the new concrete absorbs and therefore reduces atmospheric CO2.

Figure - 6 Vegetated facade

The material lends itself to a new concept of vertical garden, not only for newly built constructions, but also for the renovation of existing buildings. Unlike the current vegetated façade and vertical garden systems, the new material supports biological growth on its own surface; therefore, complex supporting structures are not required, and it is possible to choose the area of the façade to which the biological growth is to be applied. The figure shown above is a construction made out of bio concrete showing the simulation of a vegetated façade at the Aeronautical Cultural Centre.

At the same time, it has the capacity to capture solar radiation, making it possible to regulate thermal conductivity inside the buildings depending on the temperature reached. The biological concrete acts not only as an insulating material and a thermal regulator, but also as an ornamental alternative, since it can be used to decorate the façade of buildings or the surface of constructions with different finishes and shades of colour; it has been designed for the colonisation of certain areas with a variety of colours, without the need to cover an entire surface. The idea is to create a patina in the form of a biological covering or a "living" painting.

4. Challenges and issues

The field of bio cementation includes a multidisciplinary research involving experts from various fields. Though its potential has been suggested in a variety of sectors but several efforts need to be made to address key research and development questions necessary for commercial scale applications. This method is more complex than the chemical one as the microbial activity depends on many environmental factors including temperature, pH, concentrations and diffusion rates of nutrients and metabolites etc. The survival of bacteria within the building material also influences the extent of calcification.

The economic limitation of use of laboratory grade nutrient sources in field applications also restricts the use of this technology in several cases. Successful commercialization of the technique requires economical alternatives of the medium ingredients that cost as high as 60% of the total operating costs.

The above mentioned concerns limit the use of bio cement for practical applications in various fields in comparison to the traditional methods.

Conclusions and Suggestions for Future Work

The potential of bio cement has brought a new revolution in various engineering applications but still there has been much to explore in order to bring this environmentally safe, cost effective and convenient technology from lab to field scales. More exploratory works at large scale should be undertaken to determine the efficacy of bio cementation for consolidations of buildings.

Comparative studies should be done to check the feasibility of this method with that of the chemical methods which should include environmental impacts as well as cost. Long term efficacy of these bio minerals should be investigated. Efforts should also be made to improve current mathematical models for determining MICCP at macro-scales. As the successful implementation of MICCP-based technologies require experts of varying disciplines, researchers from all around the globe should work together to make this multi-disciplinary research move toward commercial scale applications at a higher pace.

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