

## **BIO-CONCRETE as Advanced and Sustainable Concrete**

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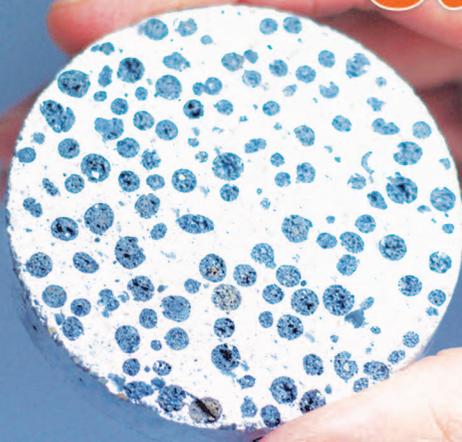
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**Abstract:** High-performance concrete is frequently used in construction practice, not only because of its high-strength qualities, but also because of its high resistance to other external influences. Therefore, many studies have been performed to improve concrete properties. There are various methods for improving concrete properties, and one of them is by employing bacteria in concrete. Bacteria play an important role in bio-concrete by promoting deterioration in porous materials, improving sand properties, sealing the concrete porosity, and enhancing the durability of building materials. Mineral precipitation that results from metabolic activities of some microorganisms has emerged as a new research area for construction materials to improve the overall properties of concrete. These bacteria can precipitate calcium carbonate ( $\text{CaCO}_3$ ) by the production of urease enzyme. The precipitation of calcium carbonate crystals occurs by heterogeneous nucleation on bacteria cell walls. Super-induced  $\text{CaCO}_3$  precipitation has been proposed as an alternative and environmentally friendly crack repair technique. Microbial carbonate precipitation decreases the permeation properties of the concrete. Hence, a deposition of a  $\text{CaCO}_3$  layer on the surface of bacteria in concrete results in decreased water absorption and porosity. In addition, bio-concrete technology represents one of the biological  $\text{CO}_2$  sequestration applications specially in bio-foamed concrete, which has high level of pores. Acceleration of carbonation process under extreme pH and anaerobic condition of bio-concrete takes place due to the bacterial enzymes reaction carbonic anhydrase (CA) and urease which acts to precipitate  $\text{CaCO}_3$  into concrete pores.

**Keywords:** Sustainable, durability, environmental, materials

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# PREFACE

High-performance concrete is frequently used in construction practice, not only because of its high-strength qualities, but also because of its high resistance to other external influences. Therefore, many studies have been performed to improve concrete properties. There are various methods for improving concrete properties, and one of them is by employing bacteria in concrete. Bacteria play an important role in bio-concrete by promoting deterioration in porous materials, improving sand properties, sealing the concrete porosity, and enhancing the durability of building materials. Mineral precipitation that results from metabolic activities of some microorganisms has emerged as a new research area for construction materials to improve the overall properties of concrete. These bacteria can precipitate calcium carbonate ( $\text{CaCO}_3$ ) by the production of urease enzyme. The precipitation of calcium carbonate crystals occurs by heterogeneous nucleation on bacteria cell walls. Super-induced  $\text{CaCO}_3$  precipitation has been proposed as an alternative and environmentally friendly crack repair technique. Microbial carbonate precipitation decreases the permeation properties of the concrete. Hence, a deposition of a  $\text{CaCO}_3$  layer on the surface of bacteria in concrete results in decreased water absorption and porosity. In addition, bio-concrete technology represents one of the biological  $\text{CO}_2$  sequestration applications specially in bio-foamed concrete, which has high level of pores. Acceleration of carbonation process under extreme pH and anaerobic condition of bio-concrete takes place due to the bacterial enzymes reaction carbonic anhydrase (CA) and urease which acts to precipitate  $\text{CaCO}_3$  into concrete pores.

This book is originally published for the first edition from Universiti Tun Hussein Onn Malaysia. Target audiences for this book are academics, researchers, and students who seek deep information on the usage of bio-concrete and reflect its contribution in the future to the global warming and to improve environmental, economic, and social impacts.

The study focuses on the utilization of bio-concrete, which is generally known as green concrete. The green concrete is a sustainable concrete, which reduces the depletion of earth natural resources. The bio-concrete will potentially improve concrete properties and lead to CO<sub>2</sub> sequestration to conserve the environment and prevent further effects of global warming.

Chapter 1 presents the background information on bio-concrete. This chapter highlights the difference of normal concrete and bio-concrete. Also, the type of bacteria used in bio-concrete and their growth curve and applications are explained in detail. Chapter 2 describes the steps for isolation of bio-concrete bacteria and producing the bacteria in powder form. Chapter 3 presents the properties of bio-concrete. Chapter 4 presents introductions, characteristics, and applications of foamed concrete. Chapter 5 discusses the enhancement on the properties of bio-foamed concrete bricks. Chapter 6 presents the potential of CO<sub>2</sub> sequestration into bio-foamed concrete bricks, which contributes to reducing the concentration of atmospheric CO<sub>2</sub> and global warming.

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With best wishes.

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# CHAPTER 1

## INTRODUCTION TO BIO-CONCRETE

### 1.0 Introduction

Recently, the application of concrete is rapidly increasing with the increasing concrete types worldwide. Many types of concrete are used in construction due to its availability and the cheap price of its material (sand/gravel/water). Today's innovation is leading to improve natural solutions for environmental impacts of the concrete to make it more sustainable and environmental friendly. The development of sustainable concrete is urgently needed for environmental reasons. The application of biotechnology to create a new type of concrete using microorganism, namely bio-concrete, is a natural way to improve concrete properties.

Concrete structures have a certain capacity for autonomous healing of such as micro-cracks. Recently, there is increasing interest in self-healing process by using bacteria that induce precipitate calcium carbonate. Calcium carbonate ( $\text{CaCO}_3$ ) precipitation using strategic bioremediation approaches involving solid-phase capture of radionuclide has been studied. The mechanism of  $\text{CaCO}_3$  formation by these bacteria is based on the enzymatic hydrolysis of urea to ammonia and carbon dioxide ( $\text{CO}_2$ ).

Bio-concrete uses bacteria that naturally produce urease. This enzyme hydrolyses urea to produce carbonate and in the presence of a calcium source,  $\text{CaCO}_3$  is readily precipitated. The metabolic activities of these microorganisms in bio-concrete result in microbial mineral precipitation, which improves the overall properties of the concrete.

Bio-concrete application is rapidly increasing and more studies on bacteria used in bio-concrete are urgently needed for environmental reasons. Several species of bacteria used in bio-concrete include:

- *Bacillus pasteurii*

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# CHAPTER 2

## ISOLATION OF BIO-CONCRETE BACTERIA

### 2.1 Introduction

The application of bacteria in concrete to improve its properties and self-healing purposes has been investigated by many researchers. One of the main challenges in utilizing bacteria in bio-concrete technology is the bacteria's survivability in the concrete under extreme pH and anaerobic conditions. Bacteria can be trained to adapt to high alkaline medium during the enrichment process or may be isolated from inorganic materials that have extreme pH, such as cementation materials. The bacterial candidate for the purposes of self-healing or CO<sub>2</sub> sequestration should be capable to produce urease and CA enzymes. Therefore, there are several processes to be conducted before selecting the bacterial species to be used in bio-concrete:

- Collecting bacterial samples
- Characterizing bacterial samples
- Isolating bacteria
- Determining the optical density of the isolated bacteria
- Selecting the most potent bacteria
- Producing the bacteria in powder form

### 2.2 Collection of bacterial samples

The characteristics of the bacteria depend on the source that they were isolated from. Sample collection may be different from one source to another. UB and SRB were collected from different sources.

- UB was collected from fresh urine
- SRB was collected from acid mire water from Sungai Pelepah, Kota Tinggi, Johor, Malaysia
- *B. tequilensis* was collected from cement kiln dust (CKD)

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# CHAPTER 3

## PROPERTIES OF BIO-CONCRETE

### 3.0 Introduction

Concrete has two phases: the first phase is when the concrete is in the fresh stage, and the second phase is at the hardened stage, which commonly occurs after 24 h of curing period and compared with a corresponding conventional concrete mix. The investigated green concrete mixes were prepared from three different types of industrial by-products, i.e. (1. Three main properties must be controlled in the fresh concrete: workability, cohesiveness, and consistency. On the other hand, for the hardened stage, the most important properties are the strength and penetration resistance of the concrete. Most studies in concrete technology have been generally focusing on concrete strength.

Nowadays, many studies have been undertaken to reduce the emission of CO<sub>2</sub> and other greenhouse gases (GHGs). Environmental issues play an important role in the sustainable development of the concrete properties. Whereas the degree of harshness conditions of the environment are increase daily due to increase of CO<sub>2</sub>. The production of bio-concrete leads to the reduction of CO<sub>2</sub> amount and improvement of the concrete properties. Different types of bacteria can be used in the concrete to produce bio-concrete. Furthermore, previous research has proved that bacteria can be used with normal concrete and concrete with other additional materials such as fly ash, biomass and silica fume and compared with a corresponding conventional concrete mix. The investigated green concrete mixes were prepared from three different types of industrial by-products, i.e.

Bacteria is one of the additional materials used to enhance the properties of concrete which can be used in different concrete types such as normal concrete, fly ash concrete, biomass concrete, and

lowest performance was recorded with 1% of SRB growth media in bio-concrete mix. After 28 days of curing, the water penetration decreased by 5.3%, 7.3%, and 8.5% for 1%, 3%, and 5% SRB media, respectively. Having bacteria in concrete could reduce its water penetration. Therefore, the durability of concrete will increase as water is prevented from seeping into the concrete to cause carbonation of steel and chlorination, which would jeopardize the strength of the structure and cause the whole building to be less durable than intended.

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# CHAPTER 4

## FOAMED CONCRETE AS A FUTURE DIRECTION OF BIO-CONCRETE APPLICATION

### 4.1 Background of foamed concrete

Foamed concrete is lightweight concrete made without coarse aggregate, which can be either cement or lime mortar, in which air-voids are generated in the mortar via a suitable aerating agent. The production of this type of concrete started early during the last century in 1920 and began commercialization in the early 1930s. Between 1930 and 1940, there was not much of its commercial applications until the end of World War II. At that time, Europe countries were the pioneers in the production and advertisement of this new concrete type, namely aerated concrete. In 1950, the United Kingdom started using this type of concrete; by 1965, nine factories had been constructed under four companies to produce foamed concrete. In 1987, foamed concrete was being produced by 35 countries where the estimation annual production worldwide was  $8.1 \times 10^8 \text{ ft}^3$  ( $23 \times 10^6 \text{ m}^3$ )<sup>2</sup> as illustrated in Figure 4.1.

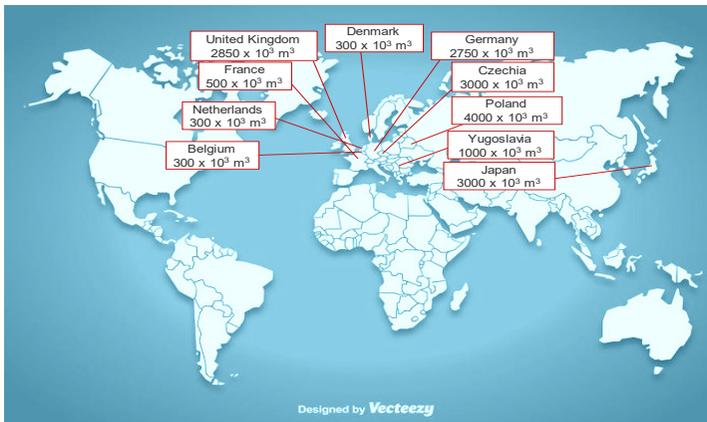


Figure 4.1: Top ten countries that produced foamed concrete in 1987

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# CHAPTER 5

## PROPERTIES OF FOAMED CONCRETE BRICKS WITH AND WITHOUT BACTERIA

### 5.0 Introduction

In this chapter, focus is given on bio-foamed concrete bricks incorporated with *B. tequilensis* (*B*). The results of compressive strength, initial water absorption, water absorption, and carbonation depth are discussed, and the performance of concrete specimens with and without *B. tequilensis* was compared at 28 days. In addition, density (D), temperature (T), and CO<sub>2</sub> concentration are all factors that influence foamed concrete properties with and without *B. tequilensis*. Therefore, FCB specimens were prepared in each experiment and tested with the same conditions of B-FCB, which were suggested via 2<sup>k</sup> factorial and RSM methods to study the compressive strength and physical properties of FCB and B-FCB. However, this chapter will not be focused on optimization of each parameter used. Therefore, the results and discussion in this chapter will only compare the performance of B-FCB and FCB under the same curing conditions.

### 5.1 Mixture and specimen's preparation

Preparation of foamed concrete depends on:

- Density adjusted
- Weight of solid materials
- Type of foaming agent used
- Specimen size
- Curing conditions
- Period of curing

There is no guidance or a standard method for designing the mix proportion of foamed concrete because the hardened concrete density of foamed concrete depends on the saturation level in its pores. The

compared to other runs. Consequently, the conditions of this run must be considered in the future research to produce high quality B-FCB. Typically, the high level of D, low level of CO<sub>2</sub> and T are the main reasons restricting the penetration of CO<sub>2</sub> in concrete.

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# CHAPTER 6

## BIO-FOAMED CONCRETE AS ENVIRONMENTALLY FRIENDLY CONCRETE

### 6.0 Introduction

There are two directions to reduce CO<sub>2</sub> emissions. First, by direct sequestration of CO<sub>2</sub> from the main source of CO<sub>2</sub>, which includes cement factories, power plants, and petroleum refineries using geological sequestration. In this method, the CO<sub>2</sub> is separated from other gas emissions into a pure form and then pumped into a geological formation deep underground or stored deep in the ocean. The second method is the biological process in which atmospheric CO<sub>2</sub> is sequestered in plants, marine sediments, and soils. However, this method is most useful for the small amount of CO<sub>2</sub> emissions.

As observed in Figure 6.1, geological technology can effectively sequester CO<sub>2</sub> from energy and industrial sources. However, CO<sub>2</sub> emission from transportation and residential areas cannot be sequestered using geological sequestration. In contrast, the bio-sequestration process can directly sequester available atmospheric CO<sub>2</sub> from any sources. As such, there is a need to develop and explore new applications for bio-sequestration technology as well as other alternative sequestration technologies to reduce CO<sub>2</sub> concentration in the atmosphere.

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