INFLUENCE OF UREOLYTIC BACTERIA (UB) ON THE ENGINEERING PROPERTIES AND MICROSTRUCTURE BEHAVIOR OF INTERLOCKING COMPRESSED EARTH BRICKS (ICEB)

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To my beloved family whom supported me throughout my journey.

To my loving mother, Zaiton Binti Merjan; father, Migat Omer Bin Ahmad and siblings, Fatin Nurul Afifah and Nur Hazwani,
Thank you for your prayers, patience, understanding and being the ones who lift me up everytime I fall down.
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ABSTRACT

Interlocking Compressed Earth Brick (ICEB) are cement stabilized soil bricks that allow for dry stacked construction. This characteristic resulted to the quick process of building walls at the same time, it requires less skilled labour as the bricks are laid dry and can easily be locked into its place. However, there are still rooms for improving the interlocking bricks by increasing its durability. Many studies had been conducted in order to improve the durability of bricks using environmental friendly method. One of the methods is by adding a certain amount of bacteria into the bricks during its production. Bacteria in brick induced calcite precipitation (calcite crystals) to cover the voids continuously. Ureolytic Bacteria (UB) is used in this study as a partially replacement of limestone water by varying the percentage at 1% UB, 3% UB and 5% UB. Enrichment process is done at soil condition to ensure the survivability of UB in ICEB environment. This research also evaluates the effect of UB in improving the engineering properties of ICEB and analyze the microstructure and morphology of UB in ICEB. Dimensional, compressive strength, water absorption and carbonation tests are performed for engineering properties, whereas X-ray fluorescence (XRF), Scanning electron microscopy (SEM) and X-ray diffraction (XRD) are analyzed for microstructure testing. The production of ICEB is carried out at Iryas Inc. (M) Sdn Bhd Industry at Sedenak, Johor and all test are conducted at Universiti Tun Hussein Onn Malaysia (UTHM) laboratory. The results for the engineering properties and microstructure analysis are compared with the control sample. It had been shown that the addition of 5% UB in ICEB indicated positive results in improving the ICEB properties by 15.25% increment in strength, 14.72% reduction in initial water absorption, 14.68% reduction in water absorption and 15.89% reduction of carbonation depth as compared with the control sample. Precipitation of calcium carbonate ($CaCO_3$) in form of calcite can be distinguished clearly in microstructure analysis. As a conclusion, addition of 5% UB in ICEB promoted the highest increment in compressive strength and the lowest reduction in water absorption as compared with the other UB percentages.

ABSTRAK

Bata saling mampat (ICEB) adalah bata tanah yang membolehkan pembinaan bangunan dijalankan tanpa menggunakan simen mortar. Oleh itu, proses pembinaan dinding bangunan adalah lebih cepat dan mengurangkan penggunaan buruh mahir. Walau bagaimanapun, terdapat banyak ruang penyelidakkan dalam meningkatkan kekuatan dan ketahanan blok saling mampat ini. Baru-baru ini pelbagai kajian telah dijalankan untuk meningkatkan ketahanan batu bata dengan menggunakan kaedah mesra alam. Salah satunya adalah dengan memperkenalkan penggunaan bakteria ke dalam batu-bata. Hal ini kerana bakteria mampu menghasil (*kristal calcite*) sebagai produk akhir hasil dari bio-kalsifikasi. Kristal-kristal ini akan menampung lompang serta rongga-rongga di dalam bata secara berterusan. Bakteria Ureolytic (UB) telah digunakan dalam kajian ini sebagai cecair pengganti air batu kapur dengan peratusan sebanyak 1%, 3% dan 5%. Proses penggayaan dilakukan dalam keadaan tanah untuk memastikan UB dapat hidup dalam persekitaran ICEB. Kajian ini juga menilai kesan UB dalam meningkatkan ciri-ciri kejuruteraan ICEB dan menganalisis mikrostruktur dan pembentukkan UB dalam ICEB. Ujian dimensi, kekuatan mampatan, penyerapan air dan pengkarbonan telah dijalankan untuk menilai sifat kejuruteraan, manakala X-ray pendarfluor (XRF), imbasan mikroskop elektron (SEM) dan X-ray pembelauan (XRD) telah dianalisis untuk ujian mikrostruktur. Pembuatan ICEB dijalankan di Iryas Inc. (M) Sdn Bhd Industri di Sedenak, Johor dan semua ujian telah dijalankan di Universiti Tun Hussein Onn Malaysia (UTHM). Keputusan bagi sifat-sifat kejuruteraan dan mikrostruktur analisis dibandingkan dengan sampel kawalan. Hasil kajian menunjukkan penambahan 5% UB ke dalam ICEB membawa peningkatan yang tertinggi dalam kekuatan sebanyak 15.25% serta pengurangan kadar awal penyerapan air sebanyak 14.72%, 14.68% pengurangan kadar serapan air dan 15.89% pengurangan kadar kedalaman pengkarbonan berbanding dengan sampel yang lain. Ini menunjukkan bahawa UB dalam ICEB menunjukkan hasil yang positif dalam meningkatkan sifat-sifat ICEB dan pemendakan kalsium karbonat ($CaCO_3$) dalam bentuk calcite boleh dilihat dengan jelas di dalam analisis mikrostruktur. Kesimpulannya, penambahan 5% UB ke dalam ICEB menunjukkan kenaikan tertinggi dalam kekuatan mampatan dan pengurangan yang paling rendah dalam penyerapan air berbanding peratusan lain.

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LIST OF SYMBOLS AND ABBREVIATIONS

kg	-	Kilogram
$CaCO_3$	-	Calcium carbonate
%	-	Percentage
Cells/ml	-	Cells per 1ml
CO_2	-	Carbon Dioxide
A	-	Cross sectional area of the sample
L	-	Litre
ml	-	Millilitre
NTU	-	Nephelometric Turbidity Unit
UB	-	Ureolytic bacteria
N/mm^2	-	Newton per milliliter square
UTHM	-	Universiti Tun Hussein Onn Malaysia
ICEB	-	Interlocking Compressed Earth Bricks
CEB	-	Compressed earth bricks
UB	-	Ureolytic Bacteria
MICP	-	Microbiologically Induced Calcite Precipitation

CHAPTER 1

INTRODUCTION

1.1 Background of study

Interlocking compressed earth brick (ICEB) masonry has the potential to provide affordable construction around the world. Comprised of basic, inexpensive materials, such as soil, the bricks can provide homes and other facilities at low cost. By creating interlocking joints between layers of bricks, ICEBs allow for the bricks to be dry stacked, without the need for mortar.

ICEB is a cost effective and sustainable construction material. ICEB construction has the potential to bring durable and affordable homes to developing countries around the world (Laursen *et al.,* 2012). Today, ICEB construction is becoming increasingly popular in developing countries including Malaysia. In Malaysia the application of interlocking brick was introduced due to the sustainable development. ICEB are energy efficient because its require less labor energy in construction process compared to the fired bricks and concrete masonry units (Maini, 2005). These reductions lower the cost of labor as much as 80% (Anand *et al.,* 2005). These advantages make ICEBs a practical and preferred construction form.

There are many types of interlocking brick develop in various part of the world. For example, Haenar bricks, the Menaco brick system, and Putra brick (Thanoon *et al.,* 2004). Although various systems were developed, the main idea of an interlocking brick system is to provide a much faster construction time. This is because interlocking brick system is dry stacked and use less mortar compared with conventional masonry construction.

Extensive research and testing have been conducted for ICEBs aiming at understanding specific compressed earth brick properties namely compressive strength, and bond characteristics based on soil and stabilization properties, optimum earth brick mix with consideration of different soil types, cement content, water content, durability and compaction of ICEBs (Burroughs, 2006; Reddy *et al.,* 2007; Bales *et al.,* 2009; Jayasinghe *et al.,* 2009). As an attempt, advancement in ICEBs technology should look into the ICEBs engineering properties improvement with addition of bacteria.

Recent development, a stronger and more durable brick has been invented incorporating a biological approach namely bacteria. This new approach is called a bio-brick which utilized bacterial mineral precipitation to increase the durability of brick. This crossbreed leads to more durable material construction and last longer. Therefore, in this study a new field of research are conducted to determine the effect of ureolytic bacteria (UB) in improving the engineering properties of ICEB.

1.2 Problem statement

Interlocking Compressed Earth Bricks (ICEB) is an example from one of five groups of IBS. ICEB is often chosen by sustainable industries as it does not require the bricks to be burnt, thus reduce the emission of carbon dioxide. The production of ICEB is also faster and effective as compared with conventional bricks. According to Maini (2005) there is a large reduction in purchased material since soil is the main ingredient in ICEB construction. The traditional masonry relies heavily on skilled labor, expensive materials and time consuming. The interlocking nature of ICEB allows for dry stacked, mortar-less construction, which reduces the need for skilled labor and shortens construction time.

Despite the advantages, ICEB also has some deficiencies. ICEB is not suitable when used in tropical environments, characterized by frequent and intense rainfall and long periods of high relative humidity. This is due to the fact that ICEBs are produced mainly from soil as the bulk ingredient, which is notorious for being prone to erosion and disintegration in water. Under the severe conditions often experienced in the humid tropics, soil-based brick often show considerable defects even over short periods of time. There are also others problems associated with ICEB namely low strength, higher water absorption, low fire resistance and high porosity (Irwan *et al.,*

2016). Water absorption is a function of clay and cement content and usually related with the strength and durability of earth bricks (Riza *et al.,* 2010). Higher rate of water absorption will results in low compressive strength and durability.

Production of ICEBs by factory were coated with chemical substances which is used to counter erosion due to long periods of high relative humidity. Consequently, the maintenance costs or even early rebuilding costs of deteriorated ICEBs structures are undesirable and unsustainable (Riza *et al.,*2010*).* Therefore, to achieve sustainable construction, environmental friendly solution should be implemented to the ICEB.

Previous studies had taken different approach to improve the properties of construction material by introducing the used of bacteria. The use of bacteria is one of new fundamental research in improving construction material in order to pursuit sustainable construction. Researcher such as Muynck *et al.,* (2008) used *Bacillus sphaericus*, Navdeep *et al.,* (2012) used *Bacillus megaterium*, Mukherjee *et al.*, (2013) used *Bacillus megaterium* and Bernardi *et al.,* (2014) used *Sporosarcina paseurii*. All bacteria used by previous studies resulted in increasing on compressive strength and reduction on water absorption by comparing control sample and treated sample with bacteria. Positive results from previous studies indicated that the successfulness of using bacteria as an environmental friendly solution in improving the durability of construction material. According to Siddique *et al.,* (2011), bacteria are able to promote the precipitation of calcium carbonate ($CaCO_3$) in the form of calcite. These calcite acts as bio-sealant by filling the pores which lead to reduction in water absorption, porosity, permeability, enhance the strength and prevent water ingression. Hence it will improve the durability of the material properties.

Even extensive of research incorporated bacteria in construction material, less knowledge were found on application of bacteria in ICEB. Ureolytic bacteria (UB) was selected for this study as an approach toward environmental solution in improving the engineering properties of ICEB. The origin of bacteria used was the same as Irwan *et al.,* (2016) study which state that UB origin was from fresh urine. Irwan *et al.,* (2016) study also reported that UB are able to improve the construction material properties by bacterial activities to producing calcium carbonate. Due to availability, locality and positive results from previous research, promote to the selection of UB toward this study. The understanding on fundamental precipitation calcium carbonate ($CaCO_3$) had been applied in this research with the use of UB to improve the durability of ICEB.

Optimum growth condition is a first attempt before using the bacteria in ICEB. Optimal growth need to be measured for ensuring high survival of the bacteria after addition in the brick. The effect of UB in the brick should be verified by evaluating engineering properties of the ICEB. Compressive strength, water absorption and carbonation are the important engineering properties that should be investigated. The existing of UB in the brick will be further investigate by microstructure and morphology analysis of the ICEB. Therefore, this research hope that an environmental friendly solution to improve the durability and properties of ICEB would be produced by introducing the used of bacteria in ICEB.

1.3 Objective

The objectives of this research are:

i. To determine optimum growth for the UB in acclimatizing soil condition.
ii. To evaluate the effect of UB in improving the engineering properties of ICEB.
iii. To investigate and analyze the microstructure and morphology of ICEB added with UB.

1.4 Scope of research

This research is mainly focused on the ways to improve the engineering properties of ICEB by introducing the use of UB. This research consists of laboratory works and field activities. Laboratory works such as enrichment process are important in order to ensure the survivability of UB bacteria in ICEB. Enrichment process of UB are performed in soil condition to suit the ICEB environment. In order to determine the effect of the bacteria in bricks, testing such as compressive strength, water absorption, carbonation, chemical properties and microstructure testing were conducted on the bricks. These following test were conducted inside the Universiti Tun Hussein Onn Malaysia (UTHM) laboratory, whereas the production of ICEB and curing was conducted in ICEB Factory, Iryas Inc. (M) Sdn Bhd at Sedenak, Johor. The addition of UB in ICEB are partially replacement of limestone water which was represent by 1%, 3% and 5% addition of bacteria during ICEB production.

The data from the test were collected and compared with the control brick to determine the effect of UB towards the ICEB. All the engineering properties testing are done for each percentage and control sample for 7^{th}, 14^{th} and 28^{th} days of testing. The microstructure test are performed for the material properties and morphology of UB to distinguish the precipitation of calcium carbonate ($CaCo_3$) in ICEB. Microstructure test such as X-ray Fluorescence (XRF), Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) were selected in this study.

1.5 Importance of research

The importance of this research is to improve the engineering properties of existing ICEB with the help of UB. Apart from that, the use of bacteria is hope to reduce the use of chemical in brick treatment and achieve an environmentally friendly for sustainable development.

1.6 Thesis outline

Chapter 1 present the introduction of the research, problem statement, objective and scope of research concerning the application of ureolytic bacteria in improving the ICEB engineering properties.

Chapter 2 provide the published works from previous studies to support the findings of this research. This chapter reviews the process of calcium carbonate, $CaCO_3$ precipitation in form of calcite. The effect of using bacteria from previous research on improving construction material properties are also overviewed.

Chapter 3 describes the experimental works used throughout this research. The materials and laboratory tests conducted under this study are elaborated in this chapter. The results obtained from the experiment were analyzed, evaluated and further discuss in Chapter 4.

Chapter 5, present the conclusion of this research and recommendations for further works.

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