Bacterial carbonate precipitation improves water absorption of interlocking compressed earth block (ICEB)

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Abstract. Interlocking compressed earth blocks (ICEB) are soil based blocks that allows for mortarless construction. The addition of many alternative materials into interlocking block in order to improve the durability has been reported. However there are currently lack of report and evidence on the application of biocalcification or microbiologically induced calcite precipitation (MICP) in improving the engineering properties of ICEB. This paper evaluate the effect of UB in improving the water absorption properties of ICEB. This paper also provide the results on SEM analysis of addition of 1%, 3% and 5% UB in ICEB. The bacteria were added as partial replacement of limestone water in ICEB. The results showed the reduction of 14.72% with 5% UB on initial water absorption followed by the results for water absorption by 24-hour soaking which also indicates reduction of 14.68% with 5% UB on 28th days of testing compared to control specimen. It was expected that the reduction of water absorption was due to the plugging of pores by the bacterial calcite which prevent ingression of water in ICEB samples. Therefore this study hopes that the positive results from the UB as improving in water absorption of ICEB will lead to improve others ICEB properties and others construction materials.

1. Introduction
Interlocking compressed earth block (ICEB) is a common construction material which was used as the building blocks for many civil structures. It can be used for all types of building from wells, houses to schools and resort buildings. ICEB is an environmental friendly construction material, cost effective, dry stacked and sustainable construction material which has potential to bring durable and affordable homes to developing counties around the world [1]. Interlocking blocks can be divided into two types based on its raw materials: soil-cement block, a soil based block which was used in this study and a concrete block, in which the major component is cement. However, there are also others problems associated with ICEB namely low strength, higher water absorption, low fire resistance and high porosity [2].

Biocalcification also known as microbiologically induced calcite precipitation (MICP), is a normal biochemical process that naturally occurs in many environments such as sea water, fresh water and
soil [3]. During this process calcium carbonate accumulates due to the activity of urease-producing microorganisms. The use of bacteria is one of new fundamental research in improving construction material in order to pursue sustainable construction. Researcher such as Willem et al. [4] used Bacillus sphaericus, Navdeep et al. [5] used Bacillus megaterium, Abhjit [6] used Bacillus megaterium and Bernardi et al. [7] used Sporosarcina paseurii. All bacteria used by previous studies resulted in reduction on water absorption by comparing control sample and treated sample with bacteria. All previous reports mentioned above demonstrated that biocalcification could be used to improve the properties of construction material. Currently, lack information on locally isolated bacteria incorporated in ICEB from Malaysia has been documented. Therefore, a study on locally isolated strains incorporating in ICEB is necessary. This study was designed to investigate the influence of microbial induced calcite precipitation on the water absorption of ICEB.

2. Experimental works
Isolated strain UB from fresh urine was used in this studies. The standard Nutrient Broth (NB) media were used to demonstrate and compare the efficiency of microbial induced calcite precipitation (MICP) by UB in ICEB. Enrichment process was done follows previous researcher method [8]. In order to ensure the survival of UB in ICEB environment, enrichment process was done with addition of soil sample to acclimatize the ICEB condition. The composition for optimal growth was 300ml nutrient broth added with 120ml of 40% urea, 1mg of soil substances and lastly 1 cyrogenic bead of ureolytic bacteria. The differences between the compositions of control were the optimal growth was done without the soil sample.

Addition of UB as partial replacement of limestone water with 1%, 3% and 5% UB are added into ICEB mix. The initial rate of water absorption test was measured on how quickly the water were being absorbed through the ICEB in 1 minute. The water absorption test was measured for 7th, 14th and 28th days. The test was carried out according to the BS 3921:1985, [9] which specify for the testing of bricks. The scanning electron microscopy (SEM) analysis was done in determination of pore size and morphology precipitation calcium carbonate (CaCO₃).

3. Water absorption
3.1 Initial water absorption
Figure 1 show the results of initial water absorption for 7th, 14th and 28th days of testing. The addition of UB as a liquid culture of 1%, 3% and 5% in ICEB reduced the initial water absorption within time compared to control specimen. The patterns of reduction water absorption are the same for all bacterial ICEB specimens. Addition of 5% UB indicates the highest reduction by 14.72% in water absorption at 28th days compared to control sample follows with 3% of UB with 11.11% and 1% of UB with 7.5%. The highest reduction of initial water absorption recorded was 3.07kg/m².min at the 28th days of testing for 5% addition of UB.

The positive result indicates the successfulness of UB surviving in ICEB environment and deposition of calcium carbonate, CaCO₃ for the water absorption improvement of ICEB. The reduction of initial water absorption with added bacteria agreed with Willem et al. [4] studies which also observed decrease in initial water absorption rate upon treatment with bacteria.
3.2 Water absorption by 24-hour of soaking

Figure 2 show the results of water absorption by 24-hour soaking for 7th, 14th and 28th days of testing. The addition of UB as a liquid culture of 1%, 3% and 5% in ICEB reduced the percentage of water absorption within time compared to control specimens. The patterns of reduction water absorption are the same for all bacterial ICEB specimen. Addition of 5% UB indicates the highest reduction by 14.68% in water absorption at 28th days compared to control sample follows with 3% of UB with 11.83% and 1% of UB with 10.73%.

According to Abhjit et al. [6], the calcite crystal acts as biosealent by filling the pores which leads to reduction in water absorption, porosity, and permeability. The presence of bacteria resulted in a significant decrease in the water absorption compared to control specimens. The deposition of a layer of calcium carbonate on the surface and inside pores of the ICEB specimens resulted in a decrease of water absorption and permeability. Hence, from the study it is clear that the presence of a layer of carbonate crystals by bacterial cells has the ability to improve the resistance of penetration of water absorption.

Figure 1. Initial water absorption of control and bacterial ICEB.

Figure 2. Results water absorption for 24-hour soaking of control and bacterial ICEB.
4. SEM analysis

Microstructure analysis using SEM image shows that UB successful to grow well inside the ICEB specimens in anaerobic condition and also capable to tolerate in alkaline environment. The pore size analysis was determine by using small size of crushed ICEB passing 64 micron sieve. Figure 3 shows the average results for pore size analyses conducted on control ICEB and bacterial ICEB. Control image generally showed rough and uneven surface. This porous surface from control samples led to increase of absorption capacity of ICEB especially water absorption and hence decrease in durability. In bacterial ICEB some part of the porous surface has been filled by calcite precipitation, thus reduction in pore size. The reduction of pore will promote to the reduction of water absorption, permeability and porosity. The appearance of calcite precipitation which can be seen as smooth surface of round sphere in bacterial ICEB microstructure image. The average size of calcite forms was evaluated and compared between control and bacterial ICEB. As shown in Figure 4, control sample which can be seen without precipitation of bacterial calcite due to 0% percentage of UB addition. Addition of 3% UB indicate highest average size of bacterial calcite form which is 12.469μm follows with 1% of UB with 9.212μm and 5% of UB by 7.815μm. Addition of 5% UB also resulted highest reduction in average pore size with 0.643μm follows with 3% UB by 0.650μm and 1% UB with 0.772μm compared to the control specimen which was 0.839μm. The calcium carbonate precipitation was to prove that addition of UB in ICEB promote to bacterial calcite precipitation.

![Figure 3. Pore measurement for ICEB with and without addition of UB.](image_url)
Based on the images obtained through Scanning electron microscope (SEM), the samples which contained bacteria has shown pores being filled and surface for these samples appear more compact and smooth compared to control which is rough and porous in nature. The appearance of calcite precipitation also can be seen clearly as smooth surface of round sphere in bacterial ICEB microstructure image. There are also decrement in pore size of bacterial ICEB compared to control ICEB. Addition of 5% UB in ICEB indicate the highest reduction of pore size compared to the control sample by 23.36%. Therefore, the results from microstructure analysis prove that by addition of UB in ICEB resulted in reducing the pores and bacterial calcite precipitation. Thus improve the water absorption of ICEB. This finding agreed with the previous studies [4-7] which indicated the improvement of material engineering properties due to deposition of calcium carbonate.

5. Conclusion

Based on the results of this study, it can be concluded that the addition of UB has positive effect on water absorption of ICEB. The present study suggests that addition of UB in ICEB resulted in improving the water absorption due to biocalcification activity of UB grown in ICEB compared to control specimens. SEM analysis shows that the successful of UB in depositing the calcium carbonate and reducing the pore size of ICEB. Hence this will further improve the properties of ICEB. This can favorably reduce the frequency of required maintenance for civil structures especially in bricks. However, further study on various parameter improvement for interlocking block manufacturing is needed. The development of a more effective process for large scale production is also necessary for practical applications in future.
6. References

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