

Unfired Bricks Green Material with Microorganism Biocementation

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Abstract: The disposal of industrial sludge from Water Treatment Plants (WTP) poses environmental risks, particularly groundwater pollution. One solution is reusing this sludge in brick production, as clay use is unsustainable and may lead to shortages. This research investigates innovations in brick making, specifically using WTP sludge and the Microbially Induced Calcite Precipitation (MICP) technique with *Bacillus huizhouensis* to enhance brick strength. The MICP method produces calcium carbonate (CaCO₃) naturally, reinforcing bricks without harmful burning. After 50 days, compressive tests showed that bio-bricks with 15% WTP sludge and 25% bacteria achieved the highest strength of 3.79 MPa, compared to 1.49 MPa for mud bricks with only sludge. However, bio-bricks with 6% bacteria and 15% sludge reached only 1.74 MPa, with all values below the SNI 15-2094-2000 standard of 5 MPa.

Keywords: *Bacillus huizhouensis*; Bricks; Clay; IPA waste sludge

Introduction

Multidisciplinary research between microbiologists and civil engineering engineers has paved the way for a new field of knowledge called geobiology. The use of microorganisms as potential catalysts in soil biocementation was first suggested by Whiffin (2004) and Mitchell & Santamarina (2005). Since then, this method has continued to be developed in the construction world. Initially, biocementation began to be applied to improve soil structure. However, biocementation through Microbially Induced Calcite Precipitation (MICP) began to be developed to make environmentally friendly materials, one of which is brick. Microbially induced calcite precipitation (MICP) is a biologically driven calcium carbonate (calcite or CaCO₃) precipitation technology, which includes the following two mechanisms namely biologically controlled and biologically induced CaCO₃ precipitation. The calcite produced will bind the soil structure so that the granules will be cemented to become stronger and stronger.

Microbially Induced Calcite Precipitation (MICP) is a soil cementation technique using calcite (CaCO₃) obtained from the cycles of living things (Syarif et al., 2020), where calcium ions (Ca²⁺) combine with carbonate ions to form calcium carbonate (CaCO₃). The formation of calcium carbonate (CaCO₃) through this method produces heterogeneous accumulations of organic and inorganic compounds that reflect the environment in which they are found, this study provides insights into the use of calcium carbonate and its surface treatments, which may be relevant to enhancing the performance of biocemented materials in unfired bricks (Ozen et al., 2013). In this research, the bacteria *Bacillus huizhouensis* is one of the facultative inorganic bacteria that can produce calcite (Zulaika et al., 2019), where calcite can bind soil grains so that the soil appears cemented (Indriani et al., 2021). The availability of these ions is key to the formation of calcite (Oyediran & Ayeni, 2020). So the MICP method can be an alternative brick hardening process to replace the burning process. One of the innovations being researched to overcome this problem

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is using environmentally friendly *Bacillus huizhouensis* bacteria to increase the strength of unfired bricks.

Bricks are widely used as the main construction material for building walls because of their durability and versatility. These bricks consist mostly of clay, to which other ingredients may or may not be added during manufacturing. It is important to know that clay is the main ingredient for making bricks, which is a non-renewable natural resource. This raises concerns about the potential scarcity of clay soil in the future if its use is not regulated (Amir & Basry, 2019). In addition, with the continuous advancement of science and technology, significant progress has been achieved in brick manufacturing innovation. Other research has investigated using unconventional materials, such as sludge sourced from Water Treatment Plants (WTP), to contribute to more sustainable or environmentally friendly brick production. The sludge disposal industry which is a by-product of the Water Treatment Plant (WTP) process needs attention because it has the potential to significantly impact the environment. This residual sludge is associated with detrimental impacts, especially soil air pollution. To overcome this problem, reusing industrial mud as a construction material is an alternative.

Research on the use of calcite-producing bacteria to strengthen bricks is still limited, therefore research was carried out on its use as a material to fill empty spaces in a test object until it reaches its strength. This research aims to determine the effect of using *Bacillus huizhouensis* bacteria as a strengthening material for bricks by using green material in the form of natural waste water treatment sludge.

Method

Time and Place

This research was conducted from February to July 2024 at the Laboratorium Program Studi Teknik Sipil Universitas Balikpapan.

Materials Used

The materials used in this research were clay, IPA waste sludge, *Bacillus huizhouensis* bacterial solution, cementation solution, and water. The use of IPA waste sludge was 15% and *Bacillus huizhouensis* bacteria had several variations, namely 6 and 25% of the dry soil weight, where the researchers took a culture age of 10 hours in this study. Then the percentage in the cementation solution is 1%. Moreover, the percentage of water proportion will be adjusted by reducing the percentage of *Bacillus huizhouensis* bacterial solution and cementation solution.

Proportion of Samples

In this research, several test object samples were made, such as mud bricks, 6% bio bricks, and 25% bio bricks. The proportions of the three test objects are described as follows: Mud bricks are bricks with a mixture of 15% mud and 85% clay and water; 6% bio bricks are bricks with 6% bacterial biocementation reinforcement, 15% mud, 85% clay, 1% cementation solution, and water; then Bio bricks 25% are bricks with 25% bacterial biocementation reinforcement, 15% mud, 85% clay, 1% cementation solution, and water. Each test object sample has three samples to find the average.

Making Bacillus huizhouensis Solution

Bacterial culture is a technique for multiplying microbes (Indriani et al., 2023). Initially, the *Bacillus huizhouensis* bacteria was in gel form, then the bacteria were cultivated in the Civil Engineering Study Program Laboratory at Balikpapan University. Bacteria were grown in a B4 medium with the composition of Urea (20 gr), Nutrient Broth (3 gr), NaHCO₃ (2.12 gr), CaCl₂.2H₂O (4.14 gr), and NH₄Cl (10 gr) mixed in distilled water per 1 liter in this experiment.

Making Cementation Solution

Cementation solution is a mixture of nutrients and chemicals used to facilitate the growth and activity of bacteria to produce calcite (Indriani et al., 2021). This study's cementation solution used 0.25 M urea and 0.25 M calcium chloride (CaCl₂.2H₂O).

Making Unfired Clay Bricks

Drying the material, before making bricks, the clay soil and natural wastewater sludge are dried using an oven 1 x 24 hours to reduce excess water content in the clay soil and natural waste water sludge samples. Material mixture, brick making process by mixing clay with IPA waste sludge as much as 15% of the total weight and *Bacillus huizhouensis* bacteria solution varying between 6 and 25%, cementation solution and water.

Formation of bricks, bricks are printed using an iron plate measuring 190 mm x 90 mm x 65 mm Module M-5a (Standar Nasional Indonesia, 2000). Then, the sample is placed in the mold and compacted using an iron pounder until it fills all corners of the mold. Drying the bricks, after the bricks are printed, the bricks are dried at room temperature so that the bacteria on the bricks can work properly. If bricks are dried directly under the sun it will cause cracks in the bricks. After 3 days, the bricks can be dried outdoors but still protected from sunlight and rain. Next, a curing period of 3, 7, 14, 39, and 50 days is carried out.

Compressive Strength Test

Based on Standar Nasional Indonesia (2000), the compressive strength of unfired bricks is classified as 50 kg/cm² or 5 MPa using a compressive strength tool (Compression Machine). Where the test equation is as follows:

$$\sigma = \frac{P}{A} \tag{1}$$

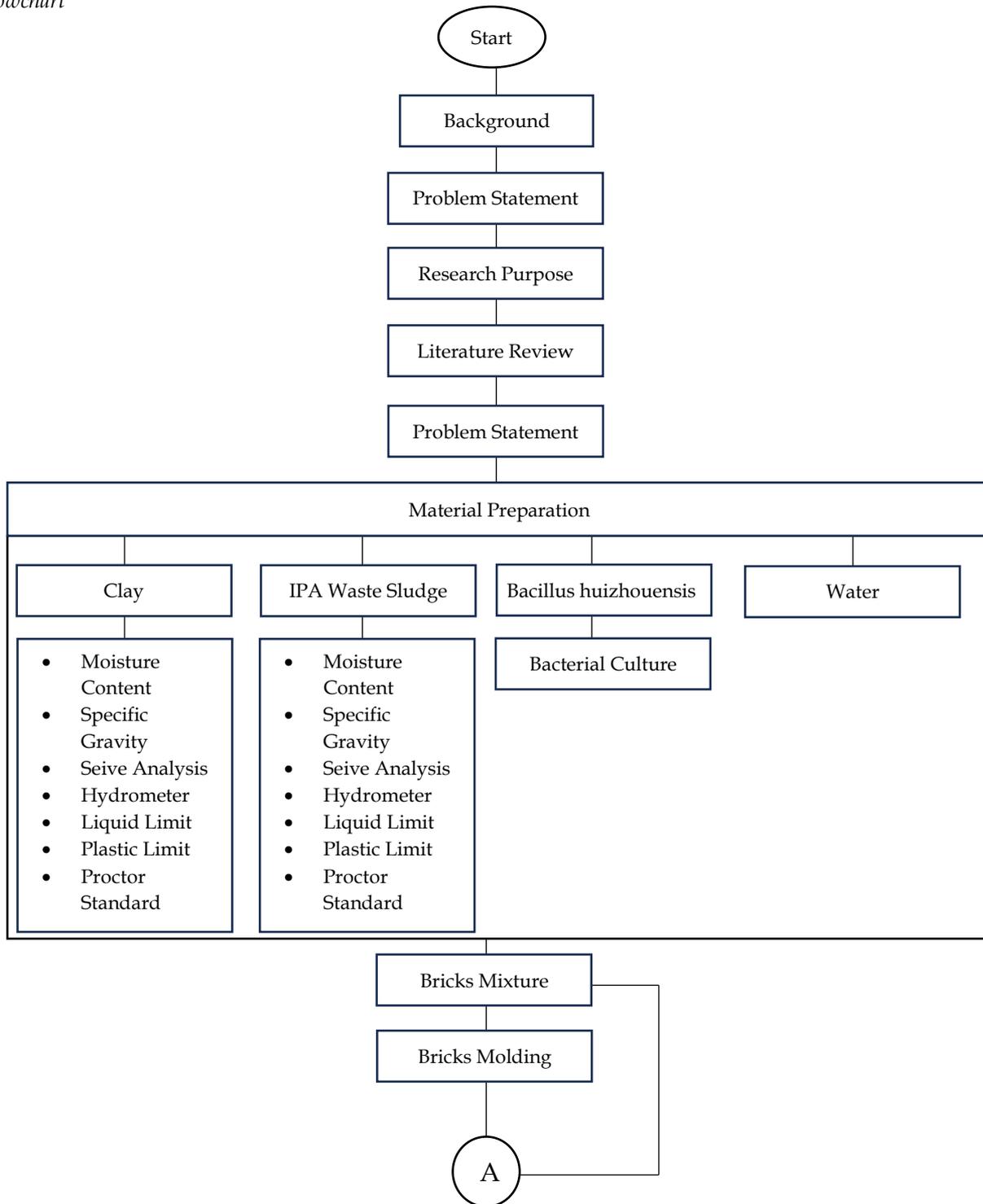
with:

σ : Compressive strength of bricks (kg/cm²)

P : Maximum load (kg)

A : Area of the object test (cm²)

Flowchart



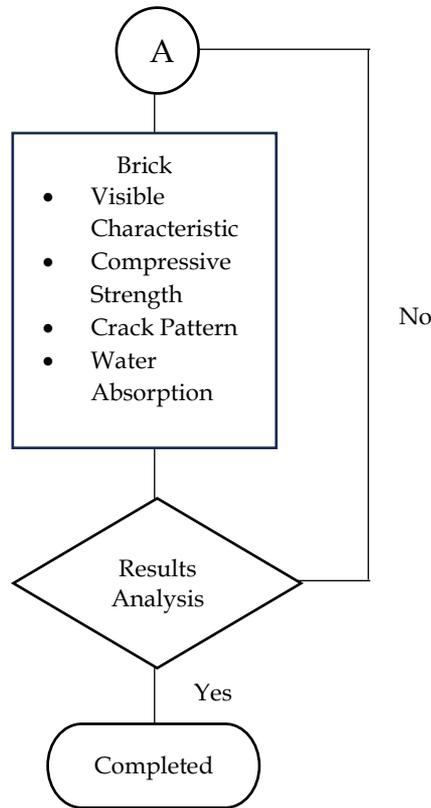


Figure 1. Flowchart

Result and Discussion

Characteristics of Sieve Analysis in Mud

In this research, sieve analysis is very important because it affects the raw material's particle size and the test object's final quality. Based on the AASHTO

classification in Hardiyatmo (2002), the results of the sieve analysis test found that the sludge was classified as coarse-grained soil (> 50% retained by the No. 200 sieve). 200 is 42.93%, the graph of which can be seen in Figure 2.

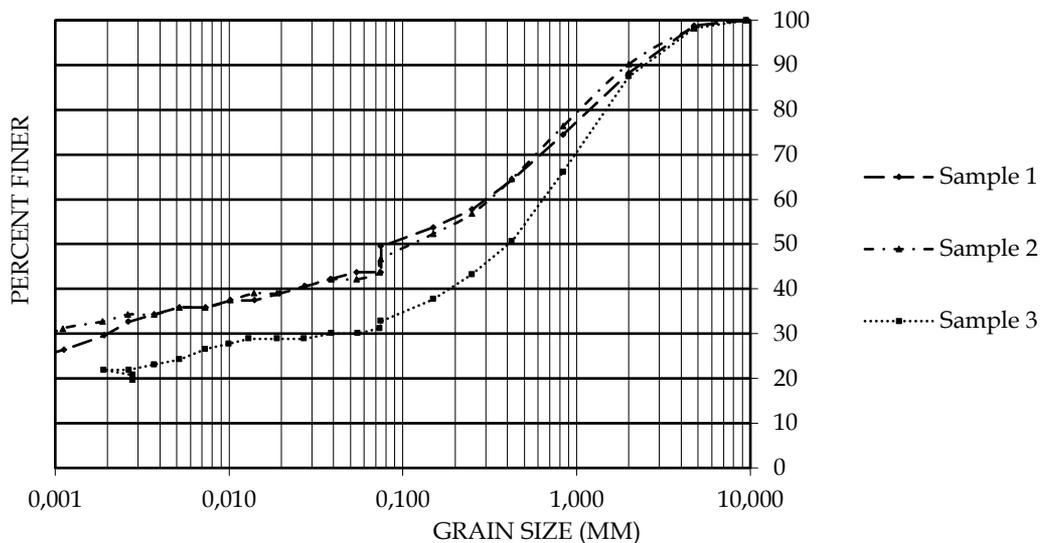


Figure 2. Distribution graph of IPA waste sludge

Results of Mud Bricks's Compressive Strength

The following are the results of testing the average compressive strength of bricks mixed with 15% waste sludge, shown in Table 1 below.

Table 1. Results of compressive strength of mud bricks

Curing time (Days)	Compressive strength value (MPa)
3	0.88
7	1.19
14	1.36
39	1.45
50	1.49

Based on Table 1, the compressive strength of the bricks continues to increase as the curing period increases. This occurs because the water content in the bricks decreases over time.

In this test, each curing period had three bricks whose average compressive strength was taken as in Table 1. It can be seen that the highest strength value was obtained during the 50 day peram period of 1.49 MPa, while the lowest strength value was obtained during the curing period. 3 days of 0.88 MPa. The two of curing periods increased, followed by the curing periods of 7, 14, and 39 days, which were 1.19, 1.36, and 1.45 MPa.

The compressive strength value of mud bricks with the addition of 15% IPA waste sludge is greater. This is relevant to research by Ni'am & Wardhono (2017), which explains that increasing the composition of mud added to bricks will further increase the compressive strength value of the bricks. Increasing the percentage of waste sludge leads to a decrease in the strength of the bricks (Apriani et al., 2023). The following graph shows the compressive strength of mud bricks, as in Figure 3.

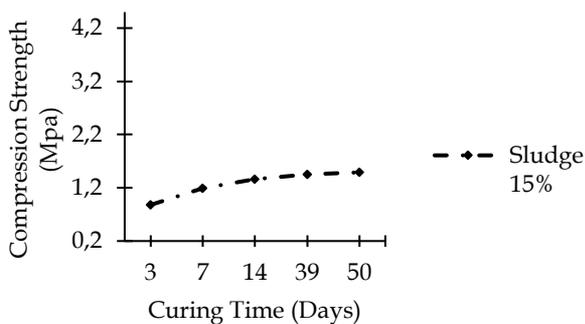


Figure 3. Results of compressive strength of mud bricks

The graph above explains that from the 3 days curing period to the 7 days curing period, there was an increase in the compressive strength value of 35.23%. Then, from the 7 to 14 days, there was an increase of 14.29%. Then, from the 14 to 39 days, there was an

increase of 6.62%. And during the 39 days leading up to the 50 days, there was an increase of 2.76%. This is by research by Dinata (2016), which explains that the longer the curing time will significantly increase the compressive strength value.

Results of Bio Bricks's Compressive Strength with 6% Bacteria

The following are the results of testing the average compressive strength of bio bricks with the addition of 15% waste sludge and 6% *Bacillus huizhouensis* bacteria, as in Table 2 below.

Table 2. Results of bio bricks's compressive strength with 6% bacteria

Culture age (Hours)	Curing time (Days)	Compressive strength value (MPa)
10	3	1.05
	7	1.38
	14	1.51
	39	1.62
	50	1.74

In this test, each curing period had three bricks whose average compressive strength was taken as in Table 2. It can be seen that the highest strength value was obtained during the 50 day curing period of 1.74 MPa, while the lowest strength value was obtained during the peram period 3 days of 1.05 MPa. The two peram periods increased, followed by the peram periods of 7, 14, and 39 days, which were 1.38, 1.51, and 1.62 MPa.

If it compares the compressive strength value of mud bricks, the compressive strength value of bio bricks is 6% greater. This is relevant to research by Hasriana et al. (2017) which explains that the results of his research indicated that test objects without bacterial treatment had lower compressive strength values compared to test objects treated with bacteria. The following is a graph of the compressive strength of 6% bio brick as in Figure 4.

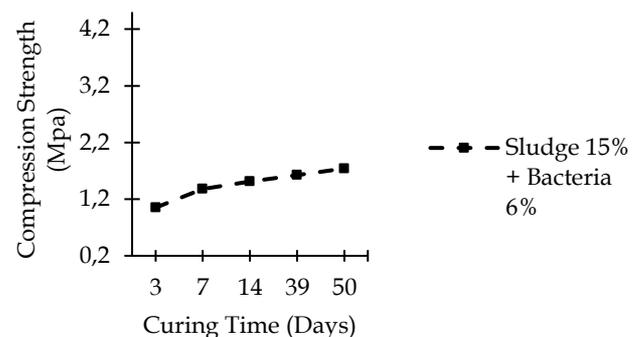


Figure 4. Results of bio bricks's compressive strength with 6% bacteria

The graph above explains that from the 3 to 7 day curing period, there was an increase in the compressive strength value of 31.43%. Then from the 7 to 14 days there was an increase of 9.42%. Then from the 14 to 39 days there was an increase of 7.28%. In the 39 days leading up to the 50 days, there was an increase of 7.40%.

Based on this, 6% bio bricks have a greater compressive strength value than mud bricks. In the 3 days, the bio of 6% bricks increased by 19.32% compared to mud bricks where mud bricks were 0.88 MPa, while the bio of 6% bricks was 1.05 MPa. Then in the 7 days, the 6% bio brick increased again by 15.97% compared to the mud brick. Mud bricks have a value of 1.19 MPa, while 6% bio bricks have a compressive strength value of 1.38 MPa. Then in the 14 days, 6% bio bricks increased by 11.03% compared to mud bricks. Mud bricks have a value of 1.36 MPa, while 6% bio bricks have a compressive strength value of 1.51 MPa. Furthermore, during the 39 days, the compressive strength value of 6% bio bricks increased by 11.72% compared to mud bricks. Mud bricks have a compressive strength value of 1.45 MPa, while 6% bio bricks have a compressive strength value of 1.62 MPa. And in the 50 days, the 6% bio brick also increased by 16.81% compared to mud brick. Mud bricks have a compressive strength value of 1.49 MPa, while 6% bio bricks have a compressive strength value of 1.74 MPa. This is in line with research by Phang et al. (2022), which explains that the addition of a bacterial solution to the test object can precipitate calcite induced by microorganisms using the Microbially Induced Calcite Precipitation (MICP) method in order to increase the compressive strength value. Anaerobic bacteria produce gas as a byproduct of their biochemical reactions during metabolism (Shan et al., 2012).

Results of Bio Bricks's Compressive Strength with 25% Bacteria

The followings are the results of testing the average compressive strength of bio-bricks with the addition of 15% waste sludge and 25% *Bacillus huizhouensis* bacteria, as in Table 3 below.

Table 3. Results of bio bricks's compressive strength with 25% bacteria

Culture age (Hours)	Curing time (Days)	Compressive strength value (MPa)
10	3	2.81
	7	3.09
	14	3.35
	39	3.56
	50	3.79

In this test, each curing period had three bricks whose average compressive strength was taken as in Table 3. It can be seen that the highest strength value was

obtained during the 50 days curing period of 3.79 MPa, while the lowest strength value was obtained during the curing period. 3 days of 2.81 MPa. The curing periods increased, followed by the curing periods of 7, 14, and 39 days, which were 3.09, 3.35, and 3.56 MPa.

If compared with the compressive strength value of mud bricks, the compressive strength value of bio bricks is 25% greater. This is relevant to research by Hadi & Saeed (2022), which explains that bacterial cementation on the test object will provide nutrients and calcium carbonate compounds useful for filling empty gaps in the test object. The addition of sludge to the brick mixture can increase water absorption, as sludge typically has more hydraulic properties than clay soil (Mizwar & Rizki, 2012). And During the curing phase, bacteria strive to adapt to their environment by producing urease enzymes to support their growth (Torano, 2022). The following is a graph of the 25% compressive strength of bio bricks, as shown in Figure 5.

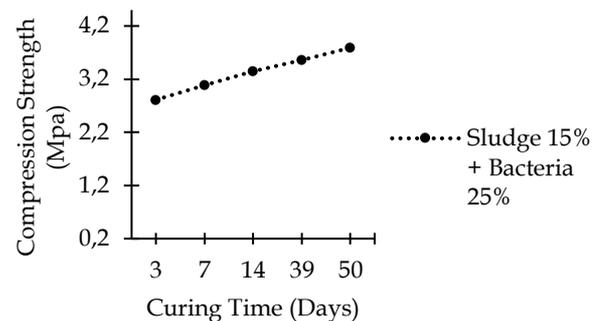


Figure 5. Results of bio bricks's compressive strength with 25% bacteria

The graph above shows that from the 3 to 7 day curing period, there was an increase in the compressive strength value of 9.96%. Then from the 7 to 14 days there was an increase of 8.41%. Then from the 14 to 39 days there was an increase of 6.27%. And in the 14 days leading up to the 50 days, there was an increase of 6.48%.

Based on this, 25% bio bricks have a greater compressive strength value than mud bricks. In the 3 days, the bio of 25% bricks increased by 219.32% compared to mud bricks where mud bricks were 0.88 MPa, while the bio of 25% bricks was 2.81 MPa. Then in the 7 days, 25% bio bricks again increased by 159.66% compared to mud bricks. Mud bricks have a value of 1.19 MPa, while 25% bio bricks have a compressive strength value of 3.09 MPa. Then in the 14 days, 6% bio bricks increased by 146.32% compared to mud bricks. Mud bricks have a value of 1.36 MPa, while 25% bio bricks have a compressive strength value of 3.35 MPa. Furthermore, during the 39 days, the compressive strength value of 25% bio bricks increased by 143.84%

compared to mud bricks. Mud bricks have a compressive strength value of 1.45 MPa, while 25% bio bricks have a compressive strength value of 3.56 MPa. In the 50 days, the 25% of bio bricks also increased by 154.36% compared to mud bricks. Mud bricks have a compressive strength value of 1.49 MPa, while 25% bio bricks have a compressive strength value of 3.79 MPa. This is in line with research by Karunagaran (2014), which proves that a more significant percentage of microorganism activity provides an excellent compressive strength value. At 10 hours of culture age, bacteria reach the stationary phase, where the number of growing bacteria equals the number of dying ones. However, bacteria can maintain themselves, resulting in a higher overall population (Sharma et al., 2021).

Comparison of Bricks's Compressive Strength

The following are the results of comparing the compressive strength of mud bricks, 6% and 25% bio bricks as in Figure 6 below.

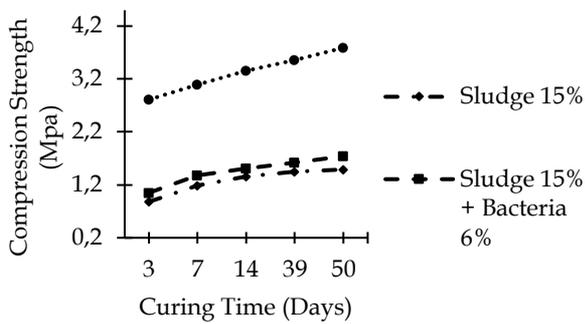


Figure 6. Graph of comparison bricks's compressive strength

The graph shows that 25% bio brick with 15% mud and 25% biocementation with *Bacillus huizhouensis* bacteria with a culture age of 10 hours produces the highest compressive strength, namely 3.79 MPa in 50 days. Based on this graph, it is known that a smaller percentage of bacteria, namely 6%, does not provide a significant compressive strength value compared to a bacteria percentage of 25%. Then, the bacterial culture's age also affects the brick's compressive strength value. At 10 hours of culture age, this is the stationary phase of bacteria, where in this phase, the number of bacteria that grow participates in biochemical reactions more than the number of bacteria that die because they help bind brick particles and produce more calcite (Mujah et al., 2016). Bricks undergo evaporation of the moisture contained in their raw materials, resulting in shrinkage (Billah et al., 2023).

Results of Biocementation of Unfired Bricks

The bricks produced are in the form of blocks with dimensions of 190 mm x 90 mm x 65 mm in accordance

with standards of Standar Nasional Indonesia (2000). In this research, *Bacillus huizhouensis* bacteria are used, which are bacteria that produce calcite through a calcium carbonate precipitation process (Zulaika et al., 2021). The results of identifying unfired bricks biocemented by microorganisms after the curing process can be seen in the following image.

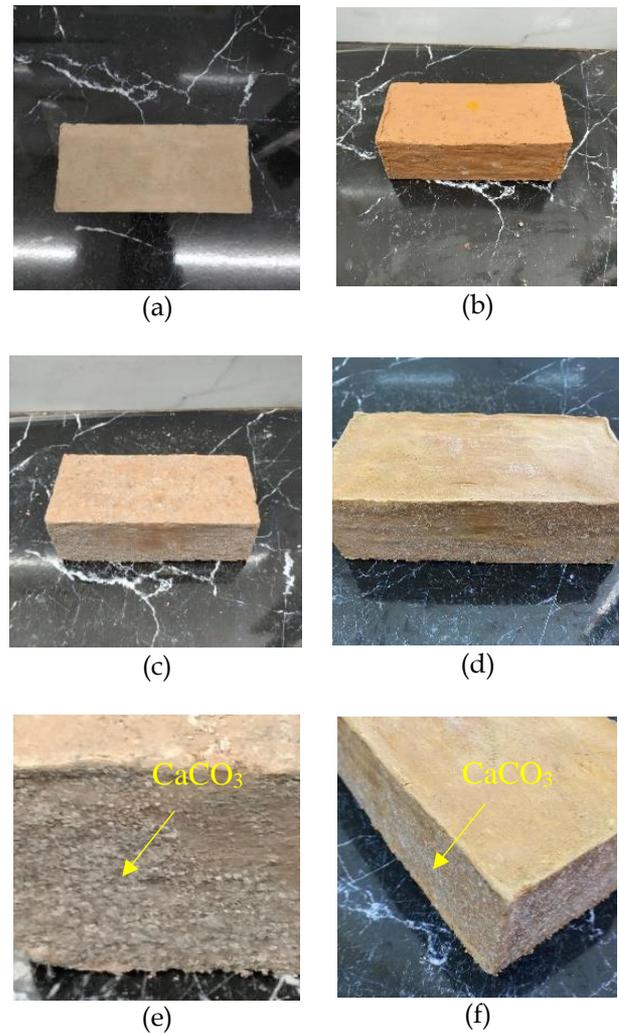


Figure 7. (a) and (b) External morphology of mud bricks, (c) and (d) External morphology of bacterial bricks, (e) Bio bricks 6% bacteria, (f) Bio bricks 25% bacteria

Biological activity can be seen after 24 hours of drying, where white spots can form or stick to the bio brick. These spots are calcium carbonate (CaCO_3) crystals found in the results of biocementation with bacteria. Some bacteria including the genus *Bacillus* can precipitate calcium carbonate, using calcium ions (Ca^{2+}) available in the environment and precipitating them (Gilmour, 2024) causing white spots to appear on bio bricks. Calcium carbonate (CaCO_3) crystals fill the pore space and bind particles (Song et al., 2022). This also indicates that the bacteria have precipitated calcium

carbonate, which indicates biological activity. However, significant variations are observed in the properties of bricks, especially in their compressive strength, depending on the composition of the bricks and the manufacturing procedures (Murmu & Patel, 2018).

Conclusion

From the compressive strength test carried out over 50 days, 25% bio brick with the addition of 15% IPA waste sludge and 25% *Bacillus huizhouensis* bacterial solution of the dry soil weight with a culture age of 10 hours produced the highest compressive strength value of 3.79 MPa compared to mud bricks with a 15% waste sludge mixture without bacterial reinforcement of 1.49 MPa. Meanwhile, 6% bio bricks with 15% IPA waste sludge and reinforced with 6% *Bacillus huizhouensis* bacteria with the same culture age, produced a compressive strength value of 1.74 Mpa. Therefore, using a higher percentage of *Bacillus huizhouensis* bacterial solution has been proven to increase the compressive strength value of bricks. However, the results do not meet the specified standards by Standar Nasional Indonesia (2000), because the compressive strength value is still below 5 MPa.

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Author Contributions

Conceptualization idea, data curation by A.M.I. and G.U. Validation and methodology by A.M.I. and M. Investigation by Y.A. and Z.Z.O. The original draft was written by A.M.I., Y.A., and Z.Z.A. Review and editing by G.U. and M. All authors have read and approved the publication of this version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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