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The Compressive Strength of Unfired Clay Brick with MICP Reinforcement

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ABSTRACT

Industrial waste in the form of sewage sludge, which is often overlooked, can have significant environmental impacts, especially polluting groundwater and surface water sources. This pollution leads to degradation of water quality, reduces the availability of clean water, and affects ecosystems. To reduce these impacts, sewage sludge can be utilized in the manufacture of construction materials, such as bricks, which is considered an economical and environmentally friendly solution. Fireless brick making, in accordance with the concept of green building, avoids air pollution from the firing process. This study explores the use of Bacillus huizhouensis bacteria in the Microbially Induced Calcite Precipitation (MICP) method to improve the strength of fireless bricks. Bacillus huizhouensis, which can hydrolyze urea and produce calcium carbonate ($CaCO_3$) or calcite, was chosen for its ability to produce $CaCO_3$ under alkaline conditions. Bacillus Huizhouensis bacteria were used to strengthen bricks with 15%, 20%, and 25% bacteria concentration variations with culture ages of 8 hours, 10 hours, and 15 hours. The results showed that the addition of 15% sewage sludge and 25% Bacillus huizhouensis bacterial solution with a culture age of 10 hours produced the highest compressive strength of 34.20 Kg/cm² (3.35 MPa), compared to sewage sludge bricks without bacteria (13.87 Kg/cm² or 1.36 MPa). Although showing significant improvement, this value is still below the SNI 15-2094-2000 standard of 50 Kg/cm² (5 MPa).

Keywords: *Sewage Sludge, Bricks, Bacteria Bacillus Huizhouensis*

INTRODUCTION

Industrial waste in the form of sewage sludge is often overlooked, yet has the potential for significant impact on the environment. Sewage sludge is often generated from various industrial processes, including the water treatment industry. The negative impact of sewage sludge on groundwater and nearby surface water sources. This can lead to degradation of water quality, reduced availability of clean water, and even affect living organisms that depend on these ecosystems [1]. Sewage sludge can be utilized as a construction material to reduce water pollution problems. With the rapid development of science leading to new discoveries, sewage sludge can be mixed as a brick making material and is considered the most economical and environmentally friendly option [2].

Bricks are one example of a type of building material that is still used in the construction of civil building construction, which is made from soil or without a mixture of other materials, burned high enough to not be destroyed when soaked. Meanwhile, the manufacture of fireless

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bricks is in accordance with the concept of green building because it can prevent air pollution due to combustion smoke and prevent the use of wood fuel [3].

One of the efforts to avoid pollution is to use environmentally friendly bacteria to increase the strength of unburned bricks [4]. The type of bacteria that is suitable for the Microbially Induced Calcite Precipitation (MICP) method is Bacillus Huizhouensis bacteria that are able to hydrolyze urea and come from urease enzyme-producing bacteria. Bacteria known to have urease enzymes come from the genus Bacillus. Bacillus is a genus of bacteria used as calcium carbonate producers, one of which is Bacillus Huizhouensis. Bacillus Huizhouensis bacteria can be used as a substitute for cement because in the process of its life cycle it can produce $CaCO_3$ (calcite) as stated in the study [5]. In fact, this bacterium can precipitate $CaCO_3$ in the form of calcite at 14 mg/ml. In addition to its ability to survive in an alkaline environment, other properties of this bacterium meet the criteria to be applied to bio-concrete.

METHOD

This research uses experimental method which is by direct research at the Laboratory of Civil Engineering Study Program, Faculty of Civil Engineering and Planning, University of Balikpapan. By sampling clay soil at Jalan Bhineka South Balikpapan and sewage sludge at Km 8 Water Treatment Plant North Balikpapan.

(a) (b)

Figure 1. Clay Soil Sampling Location (a), Sewage Sludge Sampling Location (b)

A. Laboratory Testing

Laboratory testing was carried out by taking clay soil samples and sewage sludge samples. Then tested to understand the characteristics of each sample, and carried out in accordance with testing standards can be seen in Table 1.

Table 1. Testing Standards for Clay and Sewage Sludge

No	Testing Type	Number of Test Objects	Testing Standard
1	Natural Water Content	3 sample	SNI 1965-2008
2	Specific Gravity	3 sample	SNI 03-1964-1990
3	Sieve Analysis	3 sample	SNI 03-3423-2008
4	Hydrometer	3 sample	SNI 30-3423-2008
5	Liquid Limit	4 sample	SNI 1967-2008
6	Plastic Limit	3 sample	SNI 1966-2008
7	Standard Proctor	5 sample	SNI 1742-2008

B. Growth of Bacillus Huizhouensis Bacteria

Bacterial culture is a method to breed microbes [6]. Bacillus Huizhouensis bacteria were initially in gel form, then the bacteria were cultured at the Civil Engineering Laboratory of the University of Balikpapan. Bacteria were cultured with nutrient broth medium and incubated in

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bottles. The materials needed to make medium B4 can be seen in Table 2 below.

Table 2. Materials for Making Medium B4

No	Mixing Materials	Requirement (Gram)
1	Urea	20
2	*Nutrient Broth*	3
3	$CaCI_2.2H_2O$	4,1
4	$NaHCO_3$	2,12
5	NH_4CI	10

The following are the steps for mixing medium B4 of Bacillus Huizhouens bacteria:

1. First mix the Nutrient Broth with 1 liter of water.
2. Then heat it with a stove to boil.
3. After cooling, mix the Urea solution, $CaCI_2.2H_2O$, $NaHCO_3$, and NH_4CI.
4. Then mix the bacterial isolate into medium B4.
5. Shaking the bottle so that it does not settle.
6. Bacteria were allowed to grow in the bottle at room temperature (35˚c).

(a) (b)

Figure 2. Mixing Ingredients (a), Bacteria Solution (b)

C. Preparation of cementation solution

The cementation mixture solution is used to produce calcite or calcium chloride ($CaCI_2.2H_2O$) which is useful by bacteria to produce calcite or calcium carbonate [7]. One method is known as Microbially Induced Clacite Precipitation (MICP), in which bacteria are used to induce calcium carbonate precipitation that strengthens the structure of the material and increases its strength against pressure and load. In this study, a cementation solution of 0.25 M urea and 0.25 M calcium chloride ($CaCI_2.2H_2O$) was used.

D. Compressive Strength Testing

The purpose of the brick compressive strength test is to determine the quality of bricks, verification of design strength, and quality assurance. According to SNI 15-2094-2000 the compressive strength of bricks is categorized into several classes which can be seen in Table 3 below.

Table 3. Classification of Brick Strength

Class	Average Compressive Strength of Bricks		Coefficient of Variation of The Permit
	Kg/Cm²	N/mm² (Mpa)	

50	50	5	22%
100	100	10	15%
150	150	15	15%

Source: SNI 15-2094-2000

The amount of compressive strength of bricks can be expressed by the equation:

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

Description:

σ = Brick compressive strength (Kg/Cm²)
P = Maximum load (Kg)
A = Cross-sectional area of the test piece (cm²)

RESULT

Characterization of Physical and Mechanical Properties of Clay and Sewage Sludge

Testing the characteristics of physical and mechanical properties of clay and sewage sludge to determine the classification of clay and sludge used in the study. The results of this test were obtained as shown in Table 4 below.

Table 4. Test Results of Physical and Mechanical Properties of Clay and Sewage Sludge

No	Test Type	Silt Results		Unit
		Clay Soil	Sewage Sludge	
	Physical Properties			
1	Natural Water Content	28,02	481,43	%
2	Specific Gravity	2,609	2,673	gr/cm³
3	Sieve Analysis	98,3	42,93	%
4	Hydrometer			
	a. Silt	11,25	7,57	%
	b. Clay	87,0	31,97	%
5	Liquid Limit	30,84	49,99	%
6	Plastic Limit	15,79	33,90	%
7	Plasticity Index	15,05	16,10	%
8	Classification USCS	Clay	Sandy Clay	-
	Mechanical Properties			
1	Standard Proctor			
	a. Optimum Moisture Content (OMC)	16,80	45,50	%
	b. Maximum Dry Density (MDD)	1,560	1,032	gr/cm³

Compressive Strength Testing Results

In calculating the compressive strength of brick samples, data is required from the measurement of the area of the compressive field and the value of the pressure load. Both of these data are taken using the appropriate equipment, namely to measure the area of the compressive field using a measuring instrument such as a ruler and to measure the compressive load using a compressive strength test tool (Compression Machine). The following are the results of testing the compressive strength of normal bricks (clay), bricks with 15% mud mixture, and bricks with 15%, 20%, and 25% Bacillus Huizhouensis bacteria mixture.

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A. Test Results of the Compressive Strength of Normal Bricks (Clay)

The following are the average test results of the compressive strength of normal bricks without a mixture of sewage sludge and without bacteria using only clay, as listed in Table 5 below.

Table 5. Average Results of Normal Brick Compressive Strength

No	Curring Time (Days)	Read Test Equipment (Kn)	Compressive Strength Value (Kg/Cm2)	Compressive Strength Value (MPa)
1	3	4,33	8,06	0,79
2	7	4,83	8,87	0,87
3	14	4,97	9,40	0,92

Testing the compressive strength of normal bricks (clay) at 3 days to 7 days increased by 10,13%. Then, from 7 days to 14 days there was an increase of 5,75%.

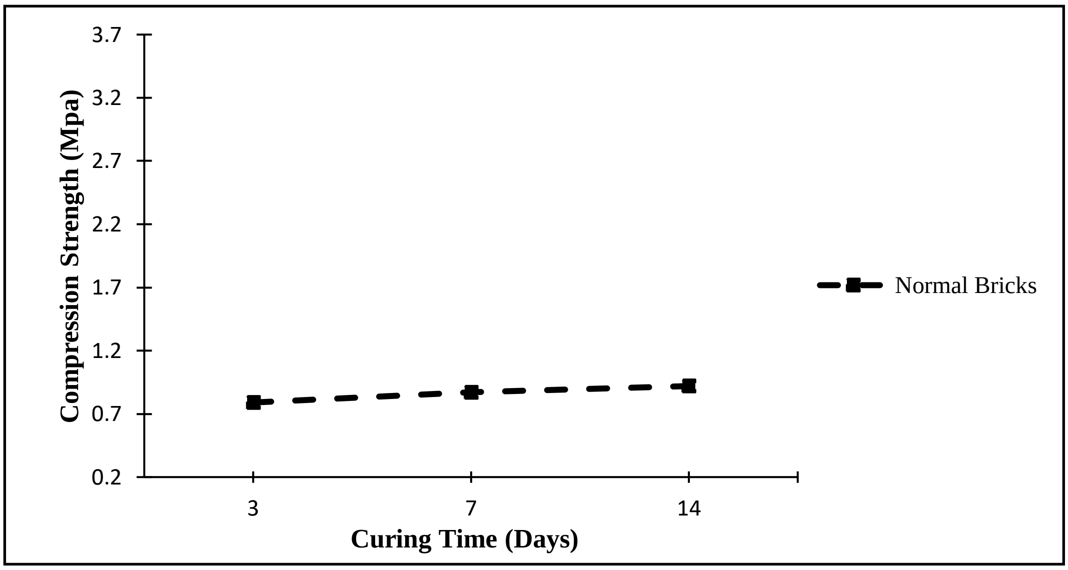

Figure 3. Results of Normal Brick Compressive Strength (Clay)

It can be seen that the curing process of 3 days, 7 days, and 14 days increases the compressive strength value. During the drying process the condition of the bricks decreases the water content, if the greater the water content it will reduce the compressive strength of the bricks. Whereas when the water evaporates the bricks experience shrinkage and compaction. Clay particles in bricks become denser and compact each other. This can increase the density of bricks and make them stronger [8].

B. Test Results of Compressive Strength with Waste Mud Mixture

The following are the average test results of the compressive strength of bricks with a 15% mixture of sewage sludge, without a mixture of bacteria can be seen in Table 6 below.

Table 6. Average Results of Brick Compressive Strength with Waste Mud Mixture

No	Curring Time	Read Test	Compressive	Compressive

	(Days)	Equipment (Kn)	Strength Value (Kg/Cm2)	Strength Value (MPa)
1	3	4,80	8,93	0,88
2	7	6,10	12,12	1,19
3	14	7,00	13,87	1,36

Testing the compressive strength of bricks with 15% mud mixture from 3 days to 7 days, there was an increase of 35,23%. Then, from 7 days to 14 days, there was an increase of 14,29%.

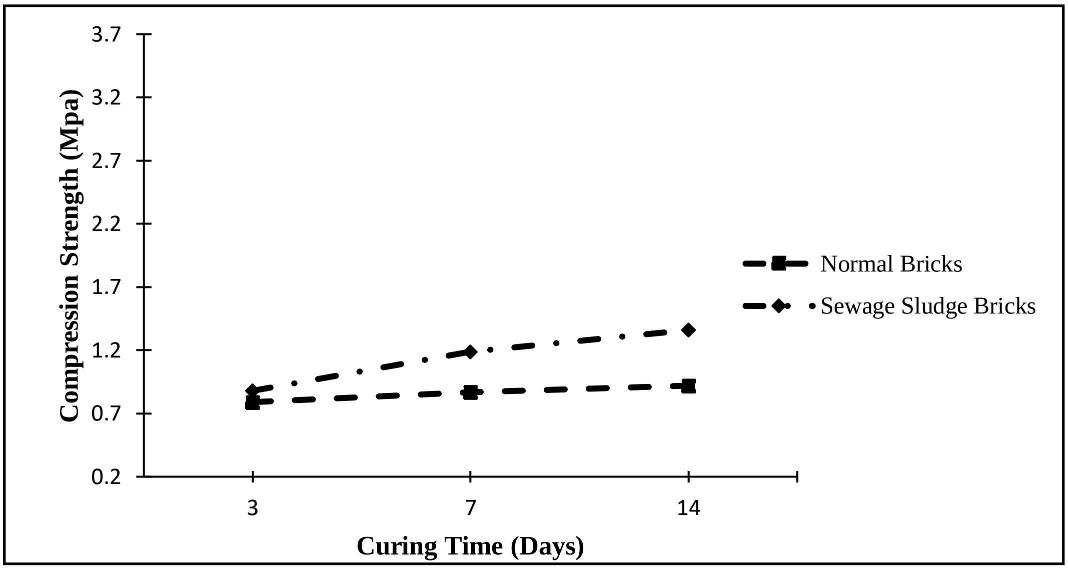

Figure 4. Results of The Compressive Strength of Bricks With a Mixture of Sewage Sludge

It can be seen that the compressive strength of bricks added with mud waste has increased compared to bricks without mud mixture. This is in line with research conducted by [9] that the more the composition of the addition of mud to the bricks, the more the compressive strength increases. Because the compressive strength is influenced by the binding force between particles of brick constituent materials, the tighter the more the compressive strength of the brick increases. Meanwhile, the length of curing time increases the density and strength of bricks, thereby reducing the water content. This is due to the evaporation of water from wet bricks so that the clay and mud particles become denser and bonded during the drying process.

C. Test Results of Compressive Strength with Waste Mud Mixture and 15% Bacteria Variation

The following are the results of testing the average compressive strength of bricks with a mixture of 15% waste mud and 15% bacterial variation with 10 hours of curing can be seen in Table 7.

Table 7. Average Results of Bricks Compressive Strength with Waste Mud Mixture and 15% Bacteria Variation

No	Curring Time	Read Test	Compressive	Compressive

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	(Days)	Equipment (Kn)	Strength Value (Kg/Cm2)	Strength Value (MPa)
1	3	12,60	22,55	2,28
2	7	13,27	25,25	2,48
3	14	13,50	25,75	2,53

Testing the compressive strength of bricks with a mixture of 15% sewage sludge and 15% bacterial variation with a culture age of 10 hours at 3 days to 7 days there was an increase of 8,77%. Then from 7 days to 14 days there was an increase of 2,02%.

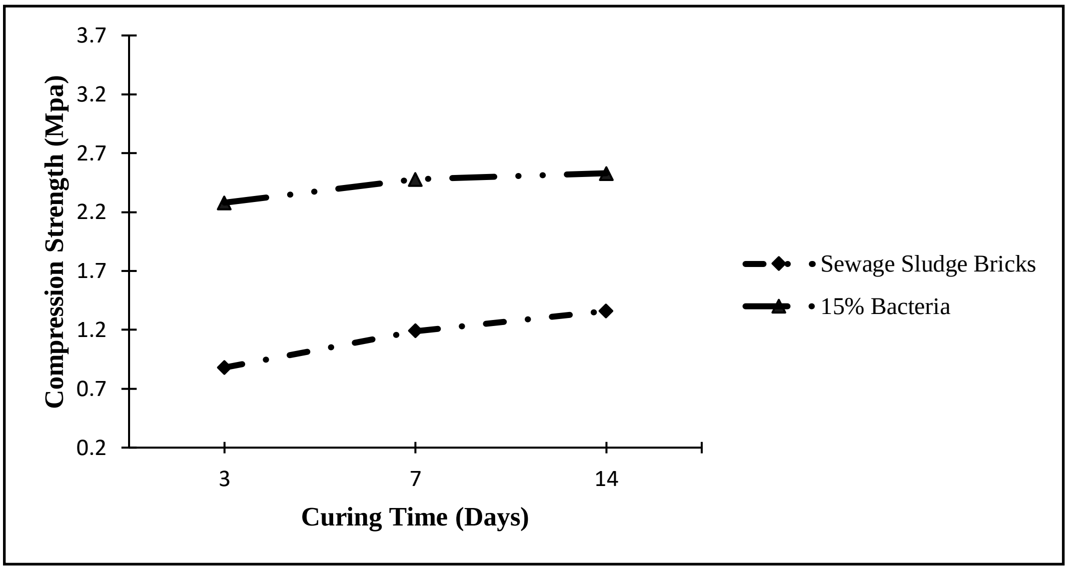

Figure 5. Comparative Results of The Compressive Strength of Sewage Sludge Bricks and Bricks With 15% Bacteria Variation

In comparison to Figure 5. The addition of 15% bacteria with a culture age of 10 hours in the 3-day curing period can increase the compressive strength value of bricks up to 159,09% of the compressive strength value of bricks without a mixture of bacteria, which was previously 0,88 Mpa to 2,28 Mpa. Then in the 7-day curing period there was an increase of up to 108,49% of the compressive strength value of bricks without a mixture of bacteria from the previous 1,19 Mpa to 2,48 Mpa. While the results of the highest value of the compressive strength of bricks in the 14-day curing period with an increase of 86,18% which was previously 1,36 Mpa to 2,53 Mpa.

It can be seen that the compressive strength value with the addition of 15% bacterial solution with a culture age of 10 hours increased from the compressive strength of bricks without a mixture of bacteria. This is in line with research conducted [10] that the addition of bacterial solutions to the soil can precipitate microbially induced calcite (MICP). This method utilizes bacterial metabolism to produce calcite ($CaCO_3$) as a binder for soil particles together which causes an increase in compressive strength. The bacterium Bacillus Huizhouensis secretes a substance that helps the formation of calcium carbonate in bricks by utilizing carbon dioxide that reacts with calcium present in bricks.

D. Test Results of Compressive Strength with Waste Mud Mixture and 20% Bacteria Variation

The following are the results of testing the average compressive strength of bricks with a mixture of 15% sewage sludge and 20% bacterial variation with 10 hours of curing can be seen in Table 8 below.

Table 8. Average Results of Bricks Compressive Strength with Waste Mud Mixture and 20% Bacteria Variation

No	Curring Time (Days)	Read Test Equipment (Kn)	Compressive Strength Value (Kg/Cm2)	Compressive Strength Value (MPa)
1	3	13,60	24,43	2,40
2	7	13,80	26,40	2,59
3	14	14,00	28,13	2,76

Testing the compressive strength of bricks with a mixture of 15% sewage sludge and 20% bacterial variation with a culture age of 10 hours at 3 days to 7 days there was an increase of 7,92%. Then from 7 days to 14 days there was an increase of 6,56%.

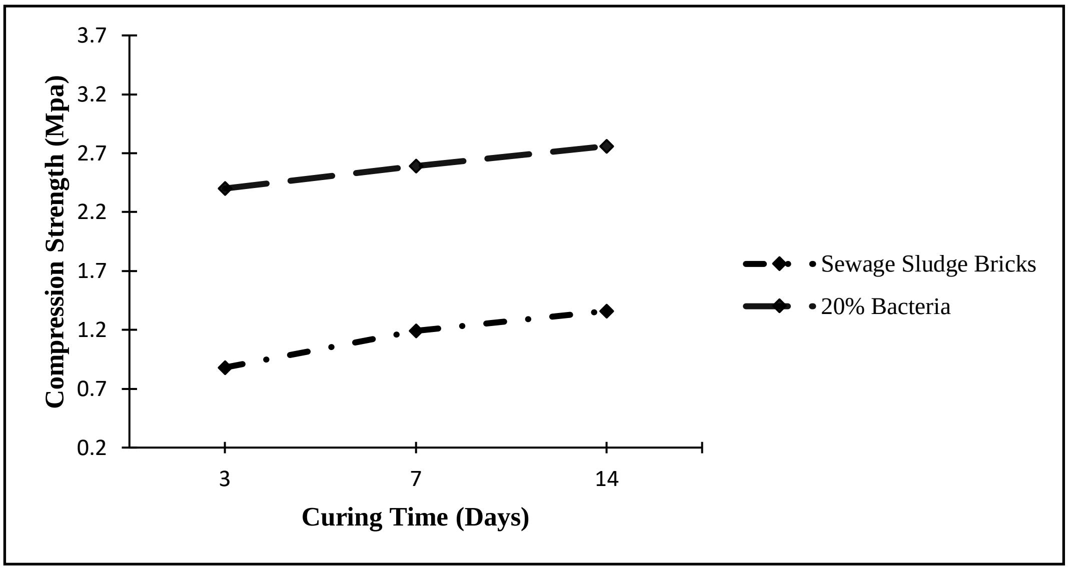

Figure 6. Comparative Results of The Compressive Strength of Sewage Sludge Bricks and Bricks With 20% Bacteria Variation

In comparison to Figure 6. The addition of 20% bacteria with a culture age of 10 hours in the 3-day curing period can increase the compressive strength value of bricks up to 172,73% of the compressive strength value of bricks without a mixture of bacteria, which was previously 0,88 Mpa to 2,40 Mpa. Then in the 7-day curing period there was an increase of up to 117,65% of the compressive strength value of bricks without a mixture of bacteria from the previous 1,19 Mpa to 2,59 Mpa. While the results of the highest value of the compressive strength of bricks in the 14-day curing period with an increase of 102,94% which was previously 1,36 Mpa to 2,76 Mpa.

It can be seen that the compressive strength value with the addition of 20% bacterial solution with a culture age of 10 hours increased from the compressive strength of bricks without a mixture of bacteria. This is in line with research [11] that in the process of making bricks will have a significant impact on compressive strength. This is due to the activity of microorganisms in changing the composition and structure of bricks. Bacteria contribute to the formation of crystal structures such as calcium carbonate that can strengthen the bricks. Meanwhile, the production of the enzyme urease is known to affect the amount of calcium carbonate formed

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in the soil. Research conducted by [12] showed that the quality of cementation using bacteria is influenced by the amount of calcium carbonate ($CaCO_3$) formed in the soil.

E. Test Results of Compressive Strength with Waste Mud Mixture and 25% Bacteria Variation

The following are the results of testing the average compressive strength of bricks with a mixture of 15% sewage sludge and 25% bacterial variation with 10 hours of curing can be seen in Table 8 below.

Table 9. Average Results of Bricks Compressive Strength with Waste Mud Mixture and 25% Bacteria Variation

No	Curring Time (Days)	Read Test Equipment (Kn)	Compressive Strength Value (Kg/Cm2)	Compressive Strength Value (MPa)
1	3	15,90	28,62	2,81
2	7	16,47	31,55	3,09
3	14	17,10	34,20	3,35

Testing the compressive strength of bricks with a mixture of 15% sewage sludge and 25% bacterial variation with a culture age of 10 hours at 3 days to 7 days there was an increase of 9,96%. Then from 7 days to 14 days there was an increase of 8,42%.

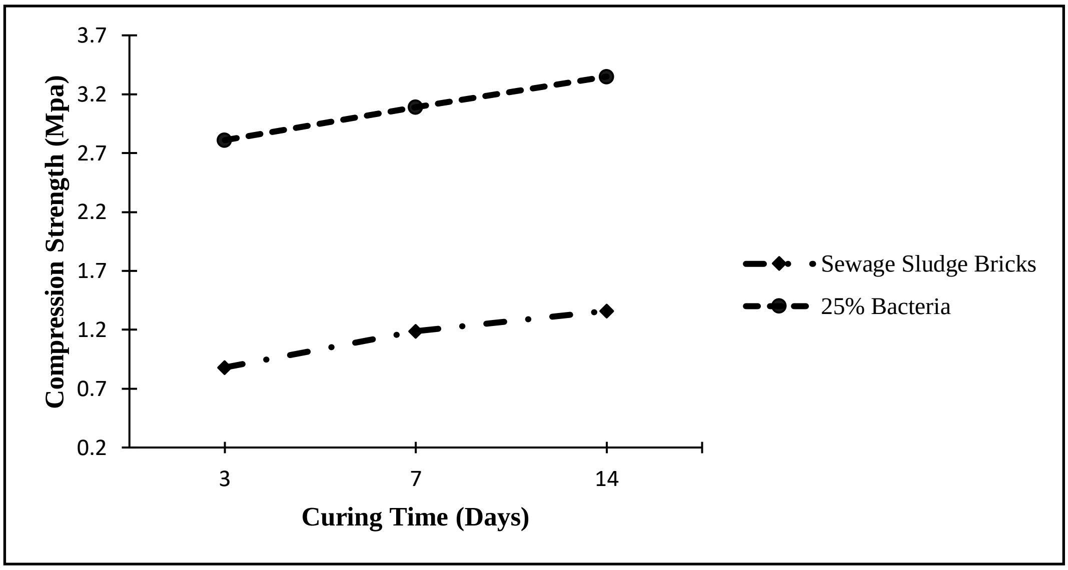

Figure 7. Comparative Results of The Compressive Strength of Sewage Sludge Bricks and Bricks With 25% Bacteria Variation

In comparison to Figure 7. The addition of 25% bacteria with a culture age of 10 hours in the 3-day curing period can increase the compressive strength value of bricks up to 219,3% of the compressive strength value of bricks without a mixture of bacteria, which was previously 0,88 Mpa to 2,81 Mpa. Then in the 7-day curing period there was an increase of up to 159,7% of the compressive strength value of bricks without a mixture of bacteria from the previous 1,19 Mpa to 3,09 Mpa. While the results of the highest value of the compressive strength of bricks in the 14-day curing period with an increase of 146,47% which was previously 1,36 Mpa to 3,35 Mpa.

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In accordance with research [13] that compressive strength increases along with the addition of bacteria caused by the process of calcite precipitation. This results in the formation of dense and strong calcite or calcium carbonate ($CaCO_3$) crystals, which stick together and result in soil hardening. The following is a comparison chart of the compressive strength testing of normal bricks, sewage sludge 15%, and Bacillus Huizhouensis bacteria variants 15%, 20%, and 25%

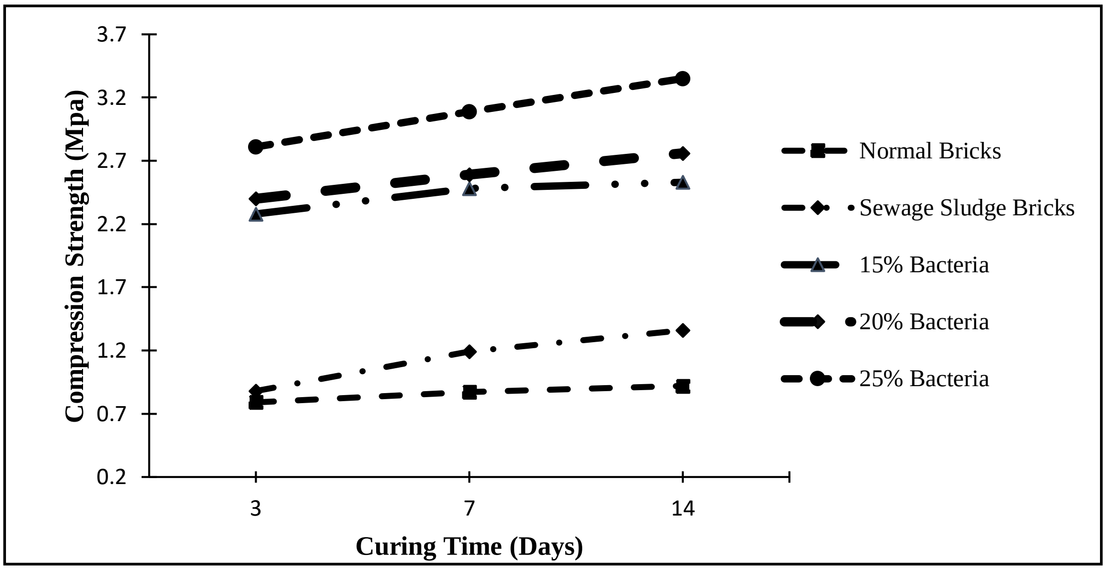

Figure 8. Compressive Strength Comparison Result

In comparison to Figure 8. The addition of Bacillus Huizhouensis bacteria at 25% with a culture age of 10 hours gives the best results in increasing the compressive strength of bricks. The production and deposition of minerals such as calcium carbonate by Bacillus Huizhouensis bacteria has reached a stable level. In line with research [14] shows that the higher the percentage of bacteria mixed into the soil, the more calcium carbonate ($CaCO_3$) will be produced. Therefore, more soil particles will be bound together. The calcium carbonate produced by Bacillus Huizhouensis bacteria results in denser bricks, which overall increases the compressive strength of the bricks. In addition, the 10-hour culture produces a higher compressive strength because the bacteria are in the stationary phase. This is also in line with research [15] that the age of bacterial culture for 10 hours is the highest phase of bacteria because the bacteria are in the stationary phase where the number of bacteria tends to increase, which means the level of calcite production also increases.

CONCLUSION

From the results of the compressive strength test at 14 days, with the addition of 15% sewage sludge and 25% Bacillus Huizhouensis bacteria at the age of 10 hours of culture produced the highest strength value of 34.20 Kg / cm² or 3,35 Mpa so as to increase the compressive strength by 146,32% compared to bricks without the addition of bacteria (with the addition of 15% sewage sludge which is 13,87 Kg / cm² or 1,36 Mpa). With this, that the addition of Bacillus Huizhouensis bacteria indicates the potential in increasing the strength of bricks. However, the resulting value still does not meet the SNI 15-2094-2000 standard of 50 Kg/Cm² or 5 Mpa.

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