THE EFFECT OF MICROBIALLY INDUCED CALCITE PRECIPITATION (MICP) ON SHEAR STRENGTH OF COAL CONTAMINATED SOIL

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ABSTRAK-- **Microbially induced calcite presipitation (MICP) adalah teknik perbaikan tanah menggunakan mikroorganisme yang dapat mengubah dan meningkatkan sifat mekanik. Teknologi ini telah dieksplorasi dan menjanjikan dengan potensi dalam berbagai aplikasi. Bakteri Bacillus subtilis sebanyak 6% ditambahkan pada tanah yang terkontaminasi batubara 5%, 10%, dan 15%. Bakteri Bacillus subtilis yang digunakan dikultur selama 3 hari dalam media tumbuh sehingga bakteri berada dalam fase stasioner. Dalam penelitian ini, uji geser langsung digunakan untuk mengetahui pengaruh pengendapan kalsit terhadap perilaku kuat geser tanah tercemar batubara. Hasil penelitian menunjukkan bahwa terjadi peningkatan nilai kohesi dan sudut gesek dalam sebagai parameter kuat geser setelah masa pemeraman. Stabilisasi MICP pada tanah terkontaminasi batubara 5% menghasilkan peningkatan kekuatan geser tiga kali lipat, sedangkan pada tanah terkontaminasi batubara 10% dan 15% terjadi peningkatan kekuatan geser tujuh kali dan lima belas kali, dibandingkan dengan tanah yang tidak diberi perlakuan.**

Kata Kunci *: MICP, kuat geser, batubara, bacillus subtilis*

ABSTRACT -- **Microbially induced calcite precipitation (MICP) is a soil improvement technique using microorganisms that can change and improve mechanical properties. This technology has been explored and is promising with potential in a variety of applications. Bacillus subtilis bacteria as much as 6% were added to soil contaminated with 5%, 10%, and 15% coal. The bacteria used were cultured for 3 days in growth medium. In this study, a direct shear test was used to determine the effect of calcite deposition on the behavior of the shear strength of coal contaminated soil. The results showed that there was an increase in the value of cohesion and internal friction angle as parameters of shear strength after the curing period. MICP stabilization in soil contaminated with 5% coal resulted in an increase in shear strength of three times, while in soil contaminated with 10% and 15% coal there was an increase in shear strength of seven times and fifteen times, compared to the untreated soil.**

Keywords : MICP, shear strength, coal, Bacillus subtilis

1 INTRODUCTION

Hundreds of thousand of hectares of ex-coal mining area were left unmanaged by the mining firm. The high expense of reclamation and the large mining area have caused the coal mining field to be abandoned. The areas still have coal that cannot be moved throughout the mining process which has an environmental impact. When sulfur-containing coal is exposed to the air, it will oxidize, resulting in Acid Rock Drainage (ARD). ARD causes a decrease in pH as well as an increase in the solubility of microelements, most of which are metal elements[1]. Various attempts to bioremediate coal-contaminated soil have been carried out to reduce lead levels and reduce environmental pollution by using the bacillus subtilis bacteria and it worked. Another effect of bioremediation using the bacillus subtilis bacteria is bio-cementation in which bacillus subtilis produces calcite in the metabolic process so that it is useful for improving soil engineering properties[2].

One of the new cementation methods is the use of microorganisms to convert soil into materials such as cemented soil (bio-cementation) (Al Qabany & Soga, 2013). Microbially induced deposition of calcite (MICP) has recently attracted a lot of attention from geotechnical engineering researchers all around the world due to its versatility and continual applicability. MICP is a naturally occurring biological process that uses bacterial metabolism to produce calcium carbonate, often known as calcite, as an in situ cementing agent (Cheng, Shahin, & Mujah, 2017). The role of bacteria or microorganisms in calcium carbonate deposition is to generating carbonates in the MICP process. (respiration, hydrolysis, etc.), increasing the pH of the environment, and acting as nucleation sites in oversaturated solutions (Shannon-Fischer et al. 1999). MICP-based soil modification technology is simpler than other soil modification technologies and has less negative environmental consequences. In comparison to conventional chemical grouting, the bacterial and cementation solution utilized in this method is easier to applied into geotechnical materials[8].

Bacillus subtilis is a rod-shaped bacteria measuring 0.5-2.5 x 1.2-10 microns, arranged in pairs or chains, where silica covers the entire surface of the cell. In critical condition, it can form spores. The antagonistic bacteria Bacillus subtilis can survive in extreme environmental conditions, namely at temperatures of -5°

C to 75° C, with an acidity level (pH) between 2-8. so it is very suitable to be used for coal-contaminated soil which has a low pH, in the dry season it has a high temperature and contains a lot of organic elements.

To determine changes in the mechanical properties of soil stabilized by MICP using Bacillus subtilis bacteria on the coal deposits in the soil, it is necessary to test several variations of coal content so it can be seen that the optimum conditions in the process of stabilization

2 MATERIALS AND METHODS

2.1 Preparation of Bacteria and Cementation Solution

Bacillus subtilis was grown in B4 medium with Urea (20 g/L), Nutrient Broth (3 g/L), NaHCO3 (2.12 g/L), CaCl2.2H2O (4.14 g/L), and NH4Cl (10 g/L) mixed in distilled water in this experiment. 0.25 M urea and 0.25 M calcium chloride were utilized in this study's cementation solution. Bacillus subtilis was cultivated with a three-day culture age. The bacteria were fed to the coal-contaminated soil at a rate of up to 6%.

2.2 Soil type

The material used in the research was taken in the area of Syarifuddin Yoes street, Balikpapan City, East Kalimantan Province. Sand and coal are taken at the same location in a conventional way using a shovel, then the material is placed in a sample sack and wrapped in plastic to maintain the natural moisture content condition. Sand and coal are taken separately and then mixed with variations show in Table 1.

Tabel 1. Variation of soil

Soil Type	Sand (%)	Coal (%)
1	95	5
2	90	10
3	85	15

The physical properties and mechanical properties of coal-contaminated sand are shown in Table 2.

Tabel 2. Soil characteristics

	Test	Test Results			Unit
		Soil Type			
		1	2	3	
Basic Properties of Sample Soil					
	Specific Gravity (Gs)	2.60	2.59	2.52	
Sieve Analysis					
a	Uniformity Coef. (Cu)	2.58	2.82	2.86	
b	Gradation Coef. (Cc)	1.47	1.69	1.80	
Engineering Properties of Sample Soil :					
Standard Proctor					
a	Maximum dry density, (γd)	1.66	1.74	1.77	g/cm^3
b	Optimum moisture content (OMC)	6.65	6.30	6.07	%
Uncofined Compression Test (UCT)					
	UCS	1.0	1.6	3.5	kPa
Direct Shear					
a	Cohesion (c)	9.8	10.1	11	kPa
b	Internal friction angle	31	33	36	°
California Bearing Ratio (CBR)					
a	Unsoaked	16	24	34	%
b	Soaked	7	12	13	%

2.3 Soil Treatment Procedures

This research blended soil, coal, the bacteria, and the cementation solutions with a mixer to ensure even distribution throughout each soil grain. In the first step, sand and coal are combined with variation composition as a plan, then added bacterial solution and cementation solution and stirred until well mixed and moulded in the PVC column with a diameter of 55 mm and a height of 20 mm. Compaction is carried out using the same compaction energy as the standard proctor, which refers to ASTM D-698, namely by converting the mould size and reducing the number of collisions to obtain a compaction energy value that is relatively close to the compaction energy obtained on the standard proctor.

The curing process and testing were carried out at 3, 7, 14 and 28 days. When curing, the sample is wrapped in plastic to prevent other bacteria from entering and growing. The sample is placed in an open room at a temperature of 25 - 30 degrees Celsius after being cured for 28 days, and there is a change in the colour of the surface of the test object, as shown in Figure 1.

(a) Before Curing	(b) After curing 28 days

Figure a. Direct Shear Sample

3. RESULTS AND DISCUSSION

3.1 Results

The results of direct shear testing on soil contaminated with 5% MICP stabilization coal showed an increase in cohesion and internal shear angle value. After a curing period of 28 days, the cohesion increased from 17 kPa to 34 kPa while the shear angle value increased from 31° to 41°. as shown in Figure 2, it can be seen that the value of cohesion and internal friction angle continues to increase with the long duration of the curing period. This behavior shows that the addition of Bacillus subtilis bacteria has a good effect on increasing the value of soil shear strength.

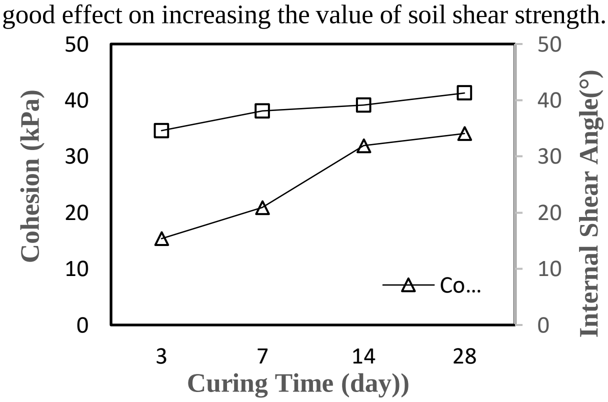


Figure 2. Graph showing the Relationship of Cohesion, Angle of Internal Shear and Curing Time for 5% Coal Contaminated Soil

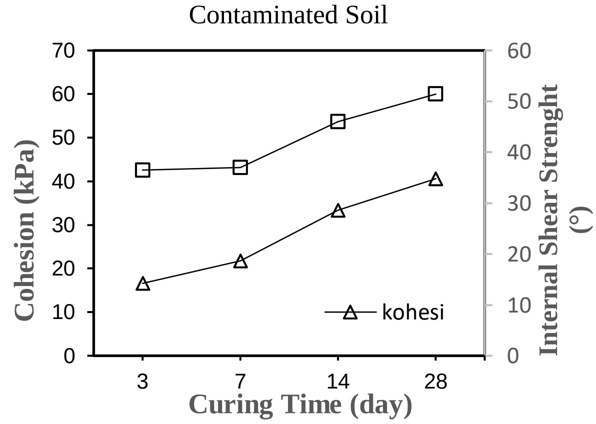


Figure 3. Graph showing the Relationship of Cohesion, Angle of Internal Shear and Curing Time for 10% Coal Contaminated Soil

As shown in Figure 3, the cohesiveness values and internal shear angles rose during the 3-day curing period, rising from 10.1 kPa to 16.6 kPa for cohesion and from 33° to 36° for the internal shear angle. The rise was greater after a 28-day of curing period, with the cohesiveness value increasing to 40.6 kPa and the internal shear angle increasing to 51°. The shear strength of soil with 10% MICP stabilization coal rose by 729%, from 12.9 kPa to 93.8 kPa.

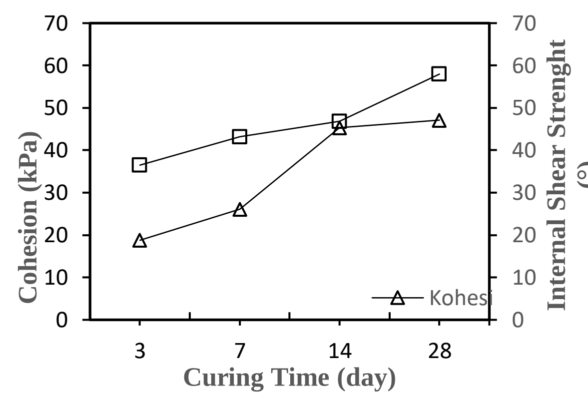
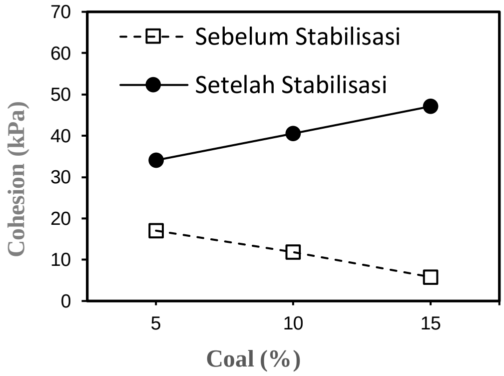


Figure 4. Graph showing the Relationship of Cohesion, Angle of Internal Shear and Curing Time of Soil Contaminated with 15% Coal

The addition of 6% Bacillus subtilis bacteria aged 3 days to soil contaminated with 15% coal enhanced the soil shear strength characteristics, as shown in Figure 4. With increasing curing time, the value of cohesiveness and internal shear angle increased. The pattern of changes in shear strength parameters tends to be the same when applied to coal polluted soil with different mixture variations. The higher the proportion of coal in the soil, the better the results for increases in soil shear strength, with a 1555% rise in shear strength from 8.3 kPa to 129.6 kPa in soil polluted with 15% coal.

Figure 5 shows the comparison of changes in soil shear strength metrics based on coal % before and after the MICP stabilizing process. As shown in Figure 5a, before MICP stabilization, the cohesiveness value decreases as the coal percentage increases, but after MICP stabilization, the cohesion value actually increases and is higher at the addition of 15% coal. If the cohesiveness value of soil contaminated with 15% coal was 5 kPa before stabilization, it climbed to 47 kPa after stabilization. Changes in the value of the direct shear angle had the same effect, with the value of the direct shear angle of 15% coal polluted soil being higher than that of 5% and 10% coal contaminated soil, as shown in Figure 5b.



(a)

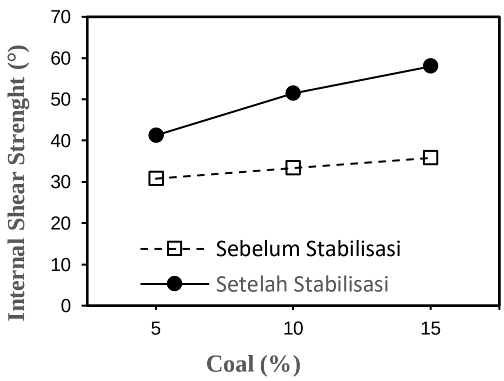


Figure 5.
a. Graph showing Cohesion Relationship with Coal Percentage
b. Graph showing Shear Angle Relationship with Coal Percentage

Figure 6 shows the differences in shear strength of each variety of coal-contaminated soil to be able to recognize what they are. The shear strength of the soil tends to decrease as the percentage of coal grows before the stabilization process, however after stabilization, the shear strength of the soil actually increases as the amount of coal increases. The shear strength of soil contaminated with 15% coal even rises to 129.6 kPa.

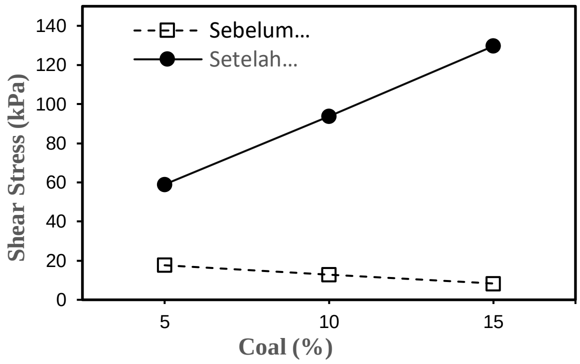


Figure 6. Graph showing Relationship between Shear Strength and Percentage of Coal

3.2 Discussion

3.2.1 Coal Addition's Effect on the MICP Process

Figure 5 shows how the addition of fine coal particles influences CaCO3 deposition and changes in shear strength parameter values. The value of the Shear stress parameter continues to rise with the addition of coal particle ≤ 0.149 mm size, commencing at 5%, 10%, and 15%. MICP stabilization led in a 334 %, 729 % ,and 1555 % increase in shear strength on soil contaminated with 5%, 10%, and 15% coal respectively.

According to Mahawish, fine particle additions of up to 25% increase CaCO3 deposition and UCS value, but fine particle additions of more than 25% cause it to decline again (Mahawish, et al: 2017).

3.2.2 The Effect of Organic Coal Content on the MICP Process

Coal is a rock that has a high organic content due to weathering plants (such as algae and other plants). Several earlier research have demonstrated that soils with organic content have a substantial effect on the MICP process, as revealed in the study of Olieviera et al. (2017). Olieviera tested urease enzyme from Canavalia ensiformis (jack bean) in powder form on several types of soil and discovered that the MICP method on soils with organic content produced better results than pure sandy soils.

The addition of organic material from coal raised the Shear stress parameter value of MICP stabilized coal contaminated soil with Bacillus Subtilis bacteria as compared to unstabilized coal contaminated soil, according to the results.

4. CONCLUSION

The inclusion of tiny coal particles affects the deposition of $CaCO_3$ as well as the value of the Shear stress parameter. The value of the Shear stress parameter continues to rise with the addition of coal particle ≤ 0.149 mm size, commencing at 5%, 10%, and 15%. MICP stabilization increased shear strength by 60% in soil contaminated with 5% coal, 155 % in soil contaminated with 10% coal, and 233 % in soil contaminated with 15% coal, respectively. The value of the coefficient uniformity (Cu) and the gradation coefficient (Cc) is increasing as the proportion of coal increases up to 15%, indicating that the grain gradation is improving. Coal is a rock that has a high organic content due to weathering plants (such as algae and other plants). When organic content from coal was added to MICP stabilized coal contaminated soil using Bacillus Subtilis bacteria, the Shear stress parameter value rose compared to unstabilized coal contaminated soil.

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