The stabilization of soft soil using admixture of palm oil boiler ash and *MATOS*

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Abstract. Banjarmasin has an alluvial area with soft soil thickness of 28-42.4m. Therefore, the land is not structurally feasible for construction due to the low California Bearing Ratio (CBR) value. One of the solutions used to overcome this problem is soil stabilization. This study aims to examine the effect of adding palm oil boiler ash and *MATOS* in accordance with CBR value to stabilize soil conditions. The laboratory CBR method was used to determine the original and stabilized conditions of the soil. The initial and stabilized soils used an admixture of 2% *MATOS* as an additive and palm oil boiler ash with percentage variations of 6%, 9%, and 12% of the dry weight soil. This was further kept for 7 days curing before being tested. The result showed that the highest CBR value is obtained at the variation of 6% palm oil boiler ash + 2% *MATOS* with an increase in CBR value of 7.542% from the original soil condition.

1. Introduction

Soft soils are low bearing capacity and high compressibility soils such as those commonly found in Banjarmasin, an alluvial area with a thickness of 28-42.4m [1]. The area is not structurally feasible for construction due to the low California Bearing Ratio (CBR) value, low permeability value, and high water saturation.

Handling soft soil in Banjarmasin is currently carried out by physical treatment, such as adding the gleam pile reinforcement, thereby, increasing the total shear strength. However, it is also important to determine the soils micro-characteristics, chemical components, and shear strength during construction. Current technological developments show that soil stabilization is not only done physically but also chemically. The success of chemical stabilization is seen from the existence of accurate initial information about the micro and chemical soil that will be stabilized. Therefore, chemical and physical characteristics on a micro scale are also important to know, especially for soft soil in Banjarmasin.

One of stabilization form is by using palm oil boiler ash and *MATOS*. Palm oil boiler ash, a waste product produced from processing palm oil, is used as a filler due to the pozzolan nature described as Siliceous, which functions as a binder of soil particles. *MATOS*, which is one of the most recent stabilization materials, is further added as an additive from industrial products. Its chemical characteristics are uniform, thereby, making it easier to use on a large scale because it is an industrial product. These chemicals function to solidify and stabilize soil in the form of a fine powder consisting of metals and inorganic mineral composition such as flour and salt. Previous studies showed that the addition of *MATOS* as an additive improves the physical and mechanical properties of clay soil.
Therefore this study examines the effect of adding MATOS and palm oil boiler ash as an additive and filler for changes in the characteristics of soft alluvial soil in the Banjarmasin area.

2. Literature Review

Boiler ash is one of the waste materials widely available from the palm oil processing industry. Previous studies have been carried out to examine boiler ash’s characterizations from the waste of the palm oil industry [2]. Furthermore, the chemical and physical characterizations were analyzed using X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD), particle size distribution, Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM). From the XRF analysis, the major component of boiler ash such as silica oxide (SiO$_2$), calcium oxide (CaO), and ferum oxide (Fe$_2$O$_3$) are determined. However, in order to produce geopolymer, the raw material need to contain 3.7% Al$_2$O$_3$, 40.60% SiO$_2$ and CaO. The median particle size of boiler ash was compared with fly ashes, an environmental material that absorb water (porosity), thereby preventing cracking. The added particles bond with soil particles and dries due to dehydration reaction. In addition, crystals form, which appear between the cement mixtures that bind the soil particles. These crystals are needle-like structures multiplied and enlarged to micron cavities that absorb water (porosity), thereby preventing cracking. MATOS works to improve the quality of road construction and also reduces the cost requirements. It reacts with soil and hydrated cement to produce complex binding particles with a strong framework and stable layer. Also, its use reduces the impact hazardous impact of dust on the environment and makes the surface waterproof in all weather.

MATOS® is an additive that functions to solidify the physical-chemical stabilizer of soils [3]. It is a fine powder material consisting of inorganic mineral composition, which tends to freeze and stabilize the soil’s physical-chemical processes. The characteristics include no odor, a pH of 8.37, a volume unit weight of 2.35gr/cm$^3$, and water solubility of 1:3 [4]. MATOS needs to be dissolved in water at a 10% molarity rate before usage. The various components negatively influence the function of topsoil, thereby reducing its level. Furthermore, the calcium cation (Ca++) in the added particles sticks directly to the soil surface. Moreover, it eliminates the inhibitory effect of ionic bonds make soil particles more easily charged with negative ions (anions). The Ca++ cation binds easily with the soil particles and helps to supply more substitute ions forming aluminum silica acid compounds. Therefore, this tends to form 3 dimensional honeycomb structures between the soil particles. When exposed to groundwater or rainfall, the added particles containing sulfur (SO$_2$) with soil in the absence of MATOS produce sulfuric acids, which causes cracks.

Conversely, in the presence of MATOS, the added particles bond with soil particles and dries due to dehydration reaction. In addition, crystals form, which appear between the cement mixtures that bind the soil particles. These crystals are needle-like structures multiplied and enlarged to micron cavities that absorb water (porosity), thereby preventing cracking. MATOS works to improve the quality of road construction and also reduces the cost requirements. It reacts with soil and hydrated cement to produce complex binding particles with a strong framework and stable layer. Also, its use reduces the impact hazardous impact of dust on the environment and makes the surface waterproof in all weather.

MATOS®s application procedure is very simple and starts by dredging and stirring with the soil until it becomes a homogeneous mixture. This process crushes large grains into smaller pieces and reduces the moisture content of the soil. MATOS is further added and stirred again to ensure a thorough mixture. Furthermore, the needed quantity of water is added to the mixture to achieve Optimum Moisture Content (OMC), making the chemical process work. Compaction is an important aspect that has to be thoroughly carried out with the appropriate equipment to achieve maximum compaction. The soils’ density increases with MATOS’s addition, which shows the results before the application’s completion. The reaction of MATOS with soil takes place within the first 24 hours, and in the first 7 days, most chemical reactions have already been completed. Furthermore, the chemical reactions tend to continue for 365 days due to the nature of MATOS and based on hydration.

In terms of soil stabilization, [5] conducted a study on increasing the free compressive strength (In terms of soil stabilization, a study was carried out on increasing the Unconfined Compressive Strength (UCS) of clay soil after adding MATOS to stabilize sand and cement [5]. The results showed that the UCS of clay before sand and cement stabilization was 3.51kg/cm$^2$ at 0% MATOS, while the stabilization of a mixture 28% sand and 6% cement was 9.10kg/cm$^2$. The addition of 2%, 4%, 6%, 8% and 10% MATOS, corresponded to the UCS values, which increased to 10.92kg/cm$^2$, 11.18kg/cm$^2$, 11.44kg/cm$^2$, 13.78kg/cm$^2$, and 14.56kg/cm$^2$ respectively. The percentage of MATOS used as an additive for this study was 2%. 

1. MATOS Super Additive is a trademark of MATOS Group.
3. Methodology

3.1. Sampling and Preparing Test Materials
The soft soil was sampled at Jl. Gubernur Syarkawi, Gambut Village, Banjar District, South Kalimantan. They were taken in disturbed and undisturbed conditions to obtain uniformity. However, this study employed the use of disturbed samples, as shown in figure 1. The test sample were prepared in the field and molded until it was ready to be tested in the Soil Mechanics Laboratory, Lambung Mangkurat University, at Banjarbaru.

The palm oil boiler ash used in this study was obtained from PT. Perkebunan Nusantara XIII Pelaihari Palm Oil Mill, Jl. Soekarno Hatta No. 1A Pelaihari, Tanah Laut District, South Kalimantan. Meanwhile, MATOS used was purchased from PT. Watukali Capita Ciptama as the manufacturer and distributor of the MATOS product brand, as shown in figure 2.

3.2. Laboratory Testing and Analysis
The laboratory test study was carried out in the Soil Mechanics Laboratory of Civil Engineering Department, Lambung Mangkurat University, Banjarbaru, South Kalimantan. The CBR test was used to determine soils in its original or initial conditions and those that have been stabilized or with additives. This test aimed to determine the CBR value of the initial and stabilized soil conditions. Then, the laboratory sequence was as follows:

- The soil samples were divided into 4 container boxes, each weighing 20 kg, with one initial and three stabilized conditions. The soil was further checked for its dry weight unit.
- The initial soil conditions were further tested for CBR to obtain the number of blows that produced the maximum CBR graph.
- The next step was preparing the stabilized soil condition samples by mixing the three container box left with palm oil boiler ash and MATOS.
- Palm oil boiler ash was initially mixed with soil samples that were crushing into smaller pieces by a percentage of 6%, 9%, and 12% of the dry weight soil in its initial condition. Each percentage was placed in a different box.
- MATOS was dissolved with water to obtain the optimum moisture content (OMC) of the initial soil sample condition. It was further mixed in the composition from the previous step using 2% of the dry weight soil.
- The soil sample mixed with MATOS further cured for 7 days, and the CBR testing was carried out with the number of blows according to the maximum graph of its initial condition.

After the laboratory test was completed, it was analyzed by comparing the CBR test result of soft soils before and after mixing the admixture of palm oil boiler ash and MATOS. This final step was carried out to determine the change of behavior in CBR value before and after the stabilization process and cured for 7 days, in order to examine the effects of adding admixtures.
4. Results And Discussion

4.1. Initial Sample Condition

The first step was to determine the optimum moisture content (OMC) of the initial soil condition with a laboratory test used to obtain the water value and open moisture contents at 70.35% and 28.76%, respectively. This means that the initial soil condition was too moist for MATOS to react because the requirement was dissolved in the OMC condition. However, irrespective of this condition, this study also examined the effect of high water content.

The initial and stabilized samples were examined using CBR Test, as shown in figure 3. Furthermore tables 1 and 2 show that the values for each variation of blows are 10, 25, and 56, with a graph used to determine the maximum stabilized conditions. The graph shows that the maximum conditions obtain from 56 blows, so the stabilized conditions will use 56 blows.

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Figure 1. Soft soil samples.  
Figure 2. MATOS soil stabilizer.

Figure 3. Result of CBR test in initial condition.
Table 1. Result of CBR test in initial condition.

| Elapsed Time (Minute) | Penetration (0.01 Mm) | 56 Blows Proving Ring 10^4 Inch Load Lbs | 25 Blows Proving Ring 10^4 Inch Load Lbs | 10 Blows Proving Ring 10^4 Inch Load Lbs |
|-----------------------|-----------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|
| 0.00                  | 0.00                  | 0.00                                    | 0.00                                    | 0.00                                    |
| 0.50                  | 63.50                 | 4.00                                    | 107.70                                  | 2.00                                    |
| 1.00                  | 127.00                | 12.00                                   | 323.11                                  | 4.00                                    |
| 1.50                  | 190.50                | 20.20                                   | 543.90                                  | 10.00                                   |
| 2.00                  | 254.00                | 29.10                                   | 783.53                                  | 10.50                                   |
| 2.50                  | 317.50                | 35.20                                   | 947.78                                  | 18.00                                   |
| 3.00                  | 381.00                | 40.20                                   | 1082.41                                 | 23.00                                   |
| 3.50                  | 444.50                | 45.50                                   | 1225.11                                 | 25.00                                   |
| 4.00                  | 508.00                | 50.30                                   | 1354.35                                 | 26.00                                   |
| 5.00                  | 635.00                | 57.50                                   | 1548.22                                 | 30.00                                   |
| 6.00                  | 762.00                | 62.50                                   | 1682.84                                 | 34.00                                   |
| 7.00                  | 889.00                | 65.60                                   | 1766.31                                 | 37.00                                   |
| 8.00                  | 1016.00               | 70.00                                   | 1884.79                                 | 40.00                                   |
| 9.00                  | 1143.00               | 74.40                                   | 2003.26                                 | 43.00                                   |
| 10.00                 | 1270.00               | 79.50                                   | 2140.58                                 | 45.00                                   |

Table 2. Result of CBR Value in initial condition.

| Blows | Load at Penetration (Lbs) | CBR Value (%) |
|-------|---------------------------|---------------|
|       | 0.1”                      | 0.2”          | 0.1”          | 0.2”          |
| 10    | 377                       | 512           | 12.57         | 11.37         |
| 25    | 283                       | 700           | 9.42          | 15.56         |
| 56    | 784                       | 1354          | 26.12         | 30.10         |

4.2. Stabilized Sample Condition
The soil sample that mixed with palm oil boiler ash and MATOS was cured for 7 days. This was followed by examining the CBR Test with 56 blows each on 3 variations of sample as shown in figure 4 and Table 3. The result shows that the combination of 6% palm oil boiler ash and 2% MATOS provided the best result after being tested with a 7 days curing period.
Figure 4. Result of CBR test in stabilized condition.

Table 3. Result of CBR test in stabilized condition.

| Elapsed Time (Minute) | Penetration (0.01 mm) | Penetration (Inch) | 6% + 2% Proving Ring 10^-4 Inch Load Lbs | 9% + 2% Proving Ring 0.0002 Cm Load Lbs | 12% + 2% Proving Ring 0.0002 Cm Load Lbs |
|-----------------------|-----------------------|--------------------|------------------------------------------|----------------------------------------|------------------------------------------|
| 0.00                  | 0.00                  | 0.00               | 0.00                                     | 0.00                                   | 0.00                                     |
| 0.50                  | 63.50                 | 0.025              | 14.00                                    | 376.96                                 | 9.00                                     | 242.33                                  |
| 1.00                  | 127.00                | 0.050              | 23.50                                    | 632.75                                 | 14.00                                    | 376.96                                  | 18.00                                    | 484.66                                  |
| 1.50                  | 190.50                | 0.075              | 30.00                                    | 807.77                                 | 19.00                                    | 511.58                                  | 23.50                                    | 632.75                                  |
| 2.00                  | 254.00                | 0.100              | 35.00                                    | 942.39                                 | 23.50                                    | 632.75                                  | 28.00                                    | 753.91                                  |
| 2.50                  | 317.50                | 0.125              | 41.50                                    | 1117.41                                | 27.50                                    | 740.45                                  | 32.00                                    | 861.62                                  |
| 3.00                  | 381.00                | 0.150              | 46.00                                    | 1238.57                                | 30.50                                    | 821.23                                  | 36.00                                    | 969.32                                  |
| 3.50                  | 444.50                | 0.175              | 51.00                                    | 1373.20                                | 34.00                                    | 915.47                                  | 40.00                                    | 1077.02                                 |
| 4.00                  | 508.00                | 0.200              | 55.00                                    | 1480.90                                | 35.50                                    | 955.86                                  | 42.00                                    | 1130.87                                 |
| 5.00                  | 635.00                | 0.250              | 61.00                                    | 1642.46                                | 40.50                                    | 1090.48                                 | 49.00                                    | 1319.35                                 |
| 6.00                  | 762.00                | 0.300              | 68.00                                    | 1830.93                                | 44.50                                    | 1198.18                                 | 55.00                                    | 1480.90                                 |
| 7.00                  | 889.00                | 0.350              | 74.00                                    | 1992.49                                | 48.50                                    | 1305.89                                 | 60.00                                    | 1615.53                                 |
| 8.00                  | 1016.0                | 0.400              | 78.50                                    | 2113.65                                | 51.50                                    | 1386.66                                 | 61.00                                    | 1642.46                                 |
| 9.00                  | 1143.0                | 0.450              | 82.50                                    | 2221.35                                | 55.00                                    | 1480.90                                 | 70.00                                    | 1884.79                                 |
| 10.00                 | 1270.0                | 0.500              | 85.50                                    | 2302.13                                | 58.50                                    | 1575.14                                 | 75.00                                    | 2019.41                                 |
Table 4. Result of CBR Value in stabilized condition.

| Admixture          | Load at Penetration (Lbs) | CBR Value (%) |
|--------------------|---------------------------|---------------|
| 6% + 2%            | 843 1456                  | 28.09 32.37   |
| 9% + 2%            | 577 996                   | 19.22 22.13   |
| 12% + 2%           | 739 1277                  | 24.64 28.40   |

4.3. Comparison and Analysis
The result obtained from the CBR Test was compared with the graph results of the initial and the stabilized condition, as shown in figure 5 and table 5. The comparison showed that the combination of 6% palm oil boiler ash and 2% MATOS graph were above the initial CBR graph, while the other admixtures were below.

This unique trend was mostly caused by the initial sample, which is too moist, while the requirement for MATOS to work efficiently was by OMC conditions. The admixture combination of 9% and 12% palm oil boiler ash showed that the moisture used for the reaction was too high, thereby reducing the density below the OMC condition. Conversely, the 6% palm oil boiler ash combination makes the moisture content closer to the OMC condition, thereby obtaining the best CBR value, which further increased to 7.542% from the original soil condition.

From this study, it is concluded that of the combination of palm oil boiler ash and MATOS as an admixture for the soft soil, changes the CBR value, which is also dependent on the initial moisture content. A moisture too far from the OMC condition tends to vary or fall below the initial condition.

This study does not discuss the effect of the chemical solution on groundwater as no test was carried out due to the limitations of time and funds. Therefore, further study is recommended to consider using MATOS, with a test carried out to investigate its effect on groundwater.

![Figure 5. Comparison between initial and stabilized condition.](image-url)
Table 5. Comparison of CBR Value in initial and stabilized condition.

| Admixture | Load at Penetration (Lbs) | CBR Value (%) |
|-----------|--------------------------|---------------|
|           | 0.1”                     | 0.2”          | 0.1”          | 0.2”          |
| Initial   | 784                      | 1354          | 26.12         | 30.10         |
| 6% + 2%   | 843                      | 1456          | 28.09         | 32.37         |
| 9% + 2%   | 577                      | 996           | 19.22         | 22.13         |
| 12% + 2%  | 739                      | 1277          | 24.64         | 28.40         |

5. Conclusion
In conclusion, the highest CBR value was obtained at the variation of 6% palm oil boiler ash and 2% MATOS, with an additional increase to 7.542% from the initial soil condition. Therefore, adding the combination of palm oil boiler ash and MATOS as an admixture for the soft soil changes CBR value behaviour. In addition, the study shows that when the soil's initial moisture is too far from the OMC condition, it falls below the initial condition.

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