Palm Oil Fuel Ash Fineness in Modifying CBR Characteristics of Peat Soil

Dila Oktarise Dwina, Nurza Purwa Abiyoga*, Ade Nurdin

Civil Engineering Department; Universitas Jambi; Jl. Jambi-Muara Bulian No. 15, Muaro Jambi, Jambi, Indonesia; diladwina@unja.ac.id; abiyoga@unja.ac.id; adenurdin@unja.ac.id

* Correspondence: e-mail: abiyoga@unja.ac.id

DOI: https://doi.org/10.33558/bentang.v12i2.9598

ABSTRACT

Palm Oil Fuel Ash (POFA) is a waste product from the palm oil industry that often causes environmental problems. Its potential as a pozzolan for soil stabilization has been proven; however, the low CaO content makes it an ineffective sole stabilization material. Some researchers suggest reducing the particle size of pozzolan materials to optimize stabilization. This research aims to evaluate the effectiveness of increasing POFA particle fineness in peat stabilization. The study uses samples stabilized with fine and coarse POFA at 30%, 35%, and 40% of the soil's dry weight. California Bearing Ratio (CBR) tests were conducted after curing for 0, 7, 14, and 28 days. Test results show that the highest CBR values for samples with fine and coarse POFA are 5.48% and 5.80%, respectively, with coarse POFA kasar performing better than fine POFA at all curing times. For samples with the same curing time, the CBR value difference between 30% and 40% POFA is less than 1.00, except for fine POFA at 40% after 28 days, which is 1.25 higher than 30%. However, the performance of peat samples with 40% fine POFA is only comparable to those with 35% coarse POFA after 28 days. Based on these results, it can be seen that POFA is more effective as a filler rather than a pozzolan material for peat soil. As a filler, coarse POFA can better enhance the stability of peat.

Keywords: CBR; particle fineness; peat; POFA; soil stabilization

1. INTRODUCTION

Palm Oil Fuel Ash (POFA) is a residual product generated from the waste of the palm oil industry and is abundant in Southeast Asian countries like Indonesia, Thailand, and Malaysia.

Copyright@2024. Universitas Islam 45
Fibers, kernels, husks, oil palm empty fruit bunches, and shells from the oil industry are collected and burnt in the power plants to produce abundant energy for industrial use. The combustion process produces a byproduct in the form of ashes called POFA. It is often dumped in open areas without any control, causing environmental and ecological problems. The disposal of POFA without proper utilization leads to severe environmental and economic issues due to the lack of economic profit and the potential for environmental pollution. To address these issues, researchers have been exploring the feasibility of using POFA, including its utilization as an alternative to pozzolanic material, which can improve the strength and durability of soil (Hani et al., 2015; Khasib & Daud, 2020; Mahmood et al., 2020). However, its use is affected by various parameters, including the percentage of replacement (Harianto et al., 2020), environmental condition (Ahmad et al., 2011), POFA particle fineness (Kroehong et al., 2011; Rajak et al., 2019), the addition of another stabilizer (Dwina et al., 2022; Hassan & Abdu, 2015; Khasib & Daud, 2020), and other variables.

The potential of POFA as a pozzolan is evident from its chemical composition. As shown in Table 1, which is sampled from a single region in Malaysia but still can reflect the common properties of POFA, POFA contains high Silicon Dioxide (SiO$_2$), which is beneficial for enhancing soil strength and durability through the calcium hydroxide formation during hydration to produce calcium silicate hydrate (C-S-H), which is a primary cementitious compound responsible for strength and binding in stabilized soil. Furthermore, the high value of combined SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ indicates strong pozzolanic potential, which is crucial for developing cementitious properties from pozzolanic reaction. Al$_2$O$_3$ and Fe$_2$O$_3$ further support pozzolanic reactions, forming calcium aluminate hydrates (C-A-H) and calcium ferrite hydrates (C-F-H). As seen from the structures of the binding gel, a considerable amount of Calcium Oxide (CaO) is needed to react with SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$. However, POFA has CaO content, which is considered low. This means the effectiveness of pozzolanic reactions is limited by the low amount of CaO, which may not be sufficient to fully react with the high content of SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ in POFA.

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide, CO$_2$</td>
<td>0.10</td>
</tr>
<tr>
<td>Silicon dioxide, SiO$_2$</td>
<td>64.90</td>
</tr>
<tr>
<td>Aluminium dioxide, Al$_2$O$_3$</td>
<td>7.96</td>
</tr>
<tr>
<td>Pottasium oxide, K$_2$O</td>
<td>7.87</td>
</tr>
<tr>
<td>Iron oxide, Fe$_3$O$_3$</td>
<td>6.78</td>
</tr>
<tr>
<td>Calcium oxide, CaO</td>
<td>5.64</td>
</tr>
<tr>
<td>Phosphorus oxide, P$_2$O$_5$</td>
<td>3.04</td>
</tr>
<tr>
<td>Magnesium oxide, MgO</td>
<td>1.74</td>
</tr>
<tr>
<td>Sulfur oxide, SO$_3$</td>
<td>0.83</td>
</tr>
<tr>
<td>Titanium oxide, TiO$_2$</td>
<td>0.57</td>
</tr>
<tr>
<td>Chlorine, Cl</td>
<td>0.25</td>
</tr>
<tr>
<td>SiO$_2$ + Al$_2$O$_3$ + Fe$_3$O$_3$</td>
<td>79.64</td>
</tr>
</tbody>
</table>

*Source: Hani et al., 2015*

A finer particle size of pozzolan material is suggested to enhance the effectivity of the pozzolanic reaction (Jaturapitakkul et al., 2011; Pourakbar et al., 2015). Finer particles have a larger surface area-to-volume ratio, which can enhance the reactivity of POFA. The dissolution rate of silica (SiO$_2$) and alumina (Al$_2$O$_3$) in finer POFA is higher and will improve the pozzolanic reactions between those chemical components and the available calcium hydroxide (even if in limited quantity) or other reactive components in the soil. Furthermore, finer particles can be more evenly distributed throughout the soil matrix, leading to more uniform stabilization (Hassan & Abdu, 2015; Kroehong et al., 2011). Finer POFA particles can also effectively fill the voids.
between soil particles, leading to a denser and more compact soil structure. This can reduce the permeability of the soil and increase its load-bearing capacity.

Most researchers combine POFA with other calcium-rich materials such as lime, gypsum, or even Portland cement to compensate for the lack of CaO in POFA. Combining POFA with these calcium-rich materials shows a positive trend with about 10%-20% by weight of the soil as the optimum amount of POFA addition (Amaludin et al., 2023; Fitriani et al., 2023; Rahmat et al., 2015). A higher percentage of POFA should be considered when used alone as a stabilization agent. Moreover, for several types of soil or a site with a harsh environment, such as peat with high acidity, it is recommended to use additional stabilization material alongside POFA.

Peat soils are rich in organic matter, which can interfere with the pozzolanic reactions between POFA and the soil. The organic acids present in peat can hinder the stabilization process by inhibiting the dissolution and subsequent reaction of silica and alumina from POFA. When subjected to a load, the fibrous and spongy nature of the organic material compresses significantly, leading to considerable settlement (Dwina et al., 2021). Its high natural moisture content can also dilute the concentration of the pozzolan and hinder the proper curing of the stabilized soil.

From 2016 to 2020, the area of palm oil plantations in Jambi Province increased significantly. As can be seen in Figure 1, the Central Statistics Agency of Jambi Province stated that around 360,000 Ha of peatlands were converted into personal or company plantations in just four four-year periods (Badan Pusat Statistik, 2021). During the palm oil production process, one of the main problems that arise is the transposal of the product. Most hauling roads were constructed with untreated peat soil and compacted low-grade soil. Some large companies could afford mid-grade crushed gravel. However, the untreated peat soil made the road's foundation capacity insufficient to carry the vehicle road. Compacting POFA on top of the peat soil before overlaying it with another bearing layer has been practiced as an alternative. However, the result of this method is still unsatisfying. As the previous research has suggested using finer POFA for stabilization, this research is focused on monitoring the performance of POFA with different fineness in stabilizing peat soil. This research aims to evaluate the effectiveness of various fineness levels of POFA in improving the stability of peat soil. The result of the research could be used to clarify whether the performance of POFA could be increased by selecting finer particles for peat soil stabilization, thus making the decision for the stabilization method easier in the field.

![Figure 1. Harvest area and palm oil production in Jambi Province through 2016-2020](image)

2. RESEARCH METHODS

This study aims to evaluate the effectiveness of POFA with finer particle size as a stabilizing agent for peat soil through the California Bearing Ratio (CBR) test. The methodology involves collecting peat soil samples from Tangkit village, Jambi Province; preparing stabilized
peat with varying proportions of POFA (30%, 35%, and 40%); and conducting a series of CBR tests to assess the mechanical improvement in the stabilized peat after the sample was cured for 0, 7, 14, and 28 days. Two groups of samples were prepared to assess the effect of the POFA finesses. The first group was treated using POFA with particle size passing sieve no. 50 and restrained at no. 100 (300μm-150μm), while the second group used POFA that passed sieve no. 20 and restrained at no. 30 (850μm-600μm). Henceforth, the first group will be called the coarse sample, and the second group will be called the fine sample.

This research used an unsoaked CBR test. For soils with extremely high water content, like peat, the difference between soaked and unsoaked conditions might be minimal since they are already saturated, making unsoaked tests still indicative of their general behavior. Additional laboratory tests are conducted to characterize the physical properties of the peat used in this research; the results are shown in Table 2. Peat with 500% water content and 80% organic matter is appropriate and a common finding in geotechnical engineering. This peat was mixed with a certain percentage of POFA in dry conditions, and then the soil's optimum moisture content and maximum dry density were also checked through a compaction test to calculate the mix design for CBR samples.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.496</td>
</tr>
<tr>
<td>Moisture content</td>
<td>506.98%</td>
</tr>
<tr>
<td>Plastic limit (PL)</td>
<td>158.57%</td>
</tr>
<tr>
<td>Liquid limit (LL)</td>
<td>84.84%</td>
</tr>
<tr>
<td>Plasticity index (PI)</td>
<td>73.73%</td>
</tr>
<tr>
<td>Organic content</td>
<td>87.62%</td>
</tr>
<tr>
<td>Ash content</td>
<td>12.38%</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Laboratory compaction test

The affecting variables considered in this research include the types of POFA used (coarse and fine), the percentages of POFA added (30%, 35%, 40%), and the curing periods (0, 7, 14, 28 days). This sample selection aims to compare the effectiveness of coarse and fine POFA in improving the CBR values of peat soil over different curing periods. Figure 2 shows the compaction test results of the treated peat. Peat treated with fine POFA tends to have a higher density and lower moisture content than peat treated with coarse POFA. It is natural to find that adding finer particles helps achieve a more graded particle size distribution, which optimizes packing density. Finer particles can move into the interstitial spaces between larger peat particles, resulting in a denser overall soil structure. However, finer particles have a larger specific surface area (surface area per unit weight) compared to coarser particles. Thus, it should be anticipated that more water is required to coat the particles and achieve adequate lubrication for compaction.

Contrary to the prediction, the test results show a lower optimum moisture content (OMC) for samples treated with finer POFA. This might be because finer particles significantly decrease the mixture's overall void ratio. As the void ratio decreases, less water is required to fill the voids and facilitate compaction, leading to a lower OMC. Additionally, given that peat initially contains high water content and organic matter in its natural state, the pore water is quickly expelled when the peat soil is compacted due to its low retention capacity. Introducing fine POFA particles helps distribute, utilize, and retain moisture within the peat, reducing the need for additional water to reach optimal compaction.

Moreover, the fine POFA particles contribute to a more uniform moisture distribution throughout the soil matrix. This distribution helps achieve better compaction as the particles fill the gaps more effectively, enhancing the soil's structural integrity. In contrast, samples treated
with coarse POFA tend to have a lower dry density and higher moisture content. This is because coarse particles do not significantly alter the void ratio, leaving larger voids that need more water. Consequently, the presence of these larger voids means that more space is available for water, preventing the coarse POFA from achieving the same level of compaction as fine POFA. Thus, the finer particles are more effective in reducing the OMC and improving the overall compaction of the peat soil.

**California bearing ratio test**

The results of the CBR test are presented in Figure 3. It is noticeable that POFA with finer particles has a less significant influence on the increment of the CBR value compared to the coarse POFA. The highest CBR values achieved by both sample sets are 5.48% and 5.80% for samples treated with fine POFA and course POFA, respectively. Throughout all curing time assessments, the performance of samples with coarse POFA is always superior to fine POFA. However, the difference becomes smaller as the curing time increases. This indicates that coarser POFA will have an immediate effect on the stabilization of peat soil. The optimum POFA addition for fine and coarse POFA is 40% by the dry soil weight, although the result difference is insignificant.

Samples tested in all different curing times only show less than 1 CBR value difference between 30% POFA and 40% POFA, except for fine POFA with a 40% ratio tested at 28 days, which has a 1.25 CBR value higher than the sample treated with 30% POFA.

As presented in Figure 4, despite its superior performance compared to its group of samples, peat stabilized by 40% fine POFA could only perform as well as peat stabilized by 35% coarse POFA after being cured for 28 days. Based on these results, it is safe to say that by using coarser particles of POFA, the time required for stabilization and the material cost will be smaller than that of using finer POFA.

**POFA fineness on peat soil stabilization**

The test results show that while most of the previous research has concluded that using finer pozzolan material could increase the effectivity of soil stabilization, some additional consideration should still be taken, especially while dealing with peat soil using POFA as a stabilization agent. The usage of POFA alone as the stabilization agent is inefficient as the chemical composition of POFA, presented in Table 1, shows that it is high in silicon dioxide content and very low in calcium oxide. This shows that POFA is more pozzolanic than cementitious; hence, its effectiveness depends on a blend with high calcium oxide material (Nukah et al., 2023). By combining POFA with lime, gypsum, egg shale, or high calcium fly ash, finer POFA particles might influence the initial rate of the pozzolanic reaction. However, while
finer particles generally have higher reactivity, there may be an optimal particle size for POFA where the reactivity is sufficient but not excessive. Overly fine particles might react too quickly or insufficiently contribute to the long-term strength gain. Slightly coarse particles might balance the rate of pozzolanic reaction and the availability of calcium hydroxide, ensuring a steady and prolonged formation of cementitious compounds (Al-Dalain et al., 2024; Nukah et al., 2023).

Figure 3. CBR test results for each curing time with different POFA percentage

Figure 4. Stabilized peat's strength development
Besides the lack of calcium oxide, peat soil is unsuitable for chemical stabilization utilizing pozzolanic reaction. Peat soil is rich in organic matter, which produces organic acids. While the reaction between POFA and calcium hydroxide to form calcium silicate hydrate (C-S-H) requires an alkaline environment, the acidity of peat soil can neutralize the alkalinity needed for this reaction, thereby hindering it (Saida et al., 2023). Moreover, peat excess moisture can dilute the concentration of reactants and slow down or prevent the pozzolanic reaction from proceeding effectively. It can also lead to improper curing conditions. Thus, stabilizing peat with POFA alone will not trigger many reactions to produce cementitious gel and strengthen the soil matrix. Instead, the POFA mixed into the soil only acts as filler material, increasing the soil’s density by filling the voids between soil particles.

While acting as filler instead of pozzolanic material, coarse POFA becomes superior due to the better drainage properties by creating water flow pathways, reducing the risk of waterlogging. Theoretically, coarser particles can also improve the frictional resistance between soil particles, more significantly increasing the shear strength of the soil compared to finer particles. Additionally, while it depends on the characteristics of the peat soil, fine filler might also increase the plasticity of the soil, making it more susceptible to moisture-induced volume changes.

4. CONCLUSION

A series of CBR tests have been done on several groups of samples with different POFA particle sizes, POFA content, and curing time. The highest CBR values for samples treated with fine and coarse POFA are 5.48% and 5.80%, respectively. Coarse POFA consistently outperforms fine POFA across all curing times. The difference in CBR values between 30% and 40% POFA is less than 1 for each curing time, except for fine POFA at 40% after 28 days, which is 1.25 higher than at 30%. Peat stabilized with 40% fine POFA performs comparably to peat stabilized with 35% coarse POFA after 28 days of curing. From these test results, it could be concluded that the effectiveness of using POFA as a single material for stabilization agent for peat soil is inefficient due to its high silicon dioxide and low calcium oxide content. Combining it with calcium-rich material would be more beneficial if the goal is to enhance the chemical performance of the peat. However, as previous research stated that finer stabilization agent leads to better results, this does not work in peat soil as peat soil’s high organic content and acidity hinder the alkaline environment required for the pozzolanic reaction between POFA and calcium hydroxide. Excess moisture in peat soil can further dilute reactants and disrupt the curing process, making chemical stabilization using POFA alone ineffective. Thus, POFA on peat soil is better to be considered as filler material. When POFA acts as a filler material rather than a pozzolanic agent, coarse POFA particles are more beneficial. They provide better drainage by creating water pathways and enhance frictional resistance between soil particles, significantly increasing the shear strength of the soil. Fine fillers might increase soil plasticity depending on peat soil characteristics, making it more susceptible to moisture-induced volume changes, negatively affecting soil stability.

REFERENCE


