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# STUDY EXPERIMENTAL ON STRENGTH CHARACTERISTICS OF ALKALI-ACTIVATED POFA TO SOIL STABILIZATION AS SUBGRADE

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**Abstract**

The subgrade's good performance is required to support the upper layers. Excessive subgrade deformation causes a degradation in pavement performance. Traditionally, cement is used to improve it, but it's environmentally unfriendly. Recently, modern methods have been needed to diminish cement use. This study aims to promote Alkali activator POFA (AAP) as a soil mixture binder for the subgrade layer. The subgrade behaviour was assessed by plate load and CBR test on soil, soil-POFA, and soil-AAP mixtures, as well as with SEM morphology observation. The soil is clayey sand with poor gradation. Applying a 2.0 KN load to soil and soil-POFA mixtures obtained decreased deformation in settlements from 3.77 to 3.21 mm. Meanwhile, the soil-AAP mixture exhibited a lower settlement of 0.86 mm only with applied a 5.0 KN load and has bearing capacity with maximum load of 45 kN. Furthermore, a significant increase in the CBR value from 4.4% to 54.0%. The soil-AAP stabilization can improve the mechanism characteristic of the soil becoming denser and reduce deformation. Incorporation of the POFA and alkali activator into soil mixtures leads to the reaction of aluminosilicate synthesis type C-S-H gel. Hence, the AAP is feasible for promoting modern stabilization.

**Keywords:**

Alkali activator;
Deformation;
POFA;
Strength;
Subgrade.

## 1 Introduction

Excellent road pavement performance is vital for traffic during the road service life. Meanwhile, achieving this depends on the bearing capacity of the sub-base course. One of the subbase courses is subgrade as the support layer. Subgrade has the potency to deform cases due to the effect of the overloads. Function the subgrade as a support layer with bearing capacity to hold the sub base and traffic loads [1]. Many cases regarding the failure of the subgrade due to over-settlement limits and lower bearing capacity. Therefore, regarding settlement limits for bearing capacity, the subgrade is 2.5 mm [2].

The stabilization method is often used to improve the subgrade. Cement and lime are popular materials for improving soft soil's physical and mechanical properties to enhance bearing capacity, and this is known as the traditional method. However, they have problems with environmental issues, especially cement. In production, the cement requires high combustion with a temperature of 1450 – 1550° C. It releases carbon dioxide ($CO_2$) into the atmosphere, which is a total emission equal to the production of cement (1 ton cement ≈ 1 ton $CO_2$) [3].

Indonesia has the largest palm oil plantation, with an estimated total amount produced in 2020 reaching 49 million tons [4]. That certainly has potency toward escalation disposal of agro-waste palm oil. In one ton the palm oil produces solid waste of 35 – 40% as the agro waste and derivative become ash as the POFA by 5% [5] [6]. Recently, the development of agro-waste for soil stabilization has been going up, and this is known as modern stabilization. Utilizing agro-waste for soil stabilization constitutes a contribution to saving the environment. Using the wastes at present for soil stabilization is environmentally friendly and economical [7]. The POFA (Palm Oil Fuel Ash) is agro-waste from a palm oil mill that is disposed to landfill in Fig. 1. The POFA is a material from the residual combustion of fibers, kernel shells, and empty fruit bunches at a boiler furnace in palm oil mill [8]. The best way to diminish the negative impact of industrial waste is by utilizing it for soil stabilization [9]. Unconcerned regarding agro-waste issues that are disposed of in landfills, especially POFA, will be affected by health and environmental issues. A view of the POFA is disposed of beside the Boiler unit in Fig. 1.

Fig. 1: The POFA is disposed of beside the Boiler furnace.

Incorporation of the POFA into soft soil can diminish the plasticity and swelling and enhance CBR value [8-9]. There is a problem with utilizing POFA solely for soil stabilization, which only slightly increases strength. The soil-POFA mixed can slightly increase unconfined compression strength [12]. Several researchers have reported that POFA is a pozzolan synthetic with silica (Si) and alumina (Al) chemical compounds like fly ash. Despite this, the POFA is considered a soil mixture before treatment. High combustion and grinding treatments lead to the best pozzolan yield and diminished carbon content [11-12].

The POFA contains active pozzolan as the precursor, and it will be reactive if an alkali activator is added (e.g., calcium). Revealed that adding calcium to POFA can produce Calcium-Silicate-Hydrate (C-S-H) and enhance the strength of mortar [15]. The means of calcium are sodium silica (Na2SiO3) and sodium hydroxide (NaOH), which are alkali activator materials. The alkali plays an important role in the reaction of synthetic rock, which was found in ancient concrete and continues to be used in modern cement [16]. Improvement of poor soil characteristics by incorporating POFA and alkali activators in the mixture is required to optimize their potency.

POFA and alkali activators are potently used as binders for soil stabilization [17]. Also, soil strength can be improved depending on POFA content, types of alkali activators, water content, and curing conditions [18]. Previous studies revealed an effective POFA content of 20 - 25%, and using sodium hydroxide of 10M was feasible to improve soil strength, economics, and practice [19]. The POFA treated on soil mixture commonly exhibited enhancement up to 15% POFA, which is feasible to apply [20].

The combination between sodium silica and sodium hydroxide (Si/Al) at ratios of 0.5, 1.0; 1.5, 2.0; 2.5, and 3.0 shows that a ratio of 2.5 and 12M molarity levels gained the higher compressive strength on pasta geopolymer in fly ash mixture [21]. Subsequently, the combination of Si/Al: 1.0, 1.5, 2.0, and 2.5 shows that a ratio of 1.5 and 16M molarity levels gained higher compressive strength on mortar geopolymer in fly ash mixture [22]. Then, the combination of Si/Al: 1.5, 2.0, and 2.5 shows that a ratio of 2.5 and 14M molarity levels gained higher compressive strength on mortar geopolymer compared to the fly ash and POFA of 75% - 25% [23]. Examination of the durability of AAP (alkali-activated POFA), when immersed in peat water, gained a slight increase in unconfined compressive strength on testing of 28 curing ages [24]. The study found that the effectivity of alkali activators was the sodium hydroxide and potassium hydroxide obtained, enhancing the bearing capacity of soil stabilization with sodium hydroxide [19].

Many studies have conducted assessments to understand the behaviour of soil after stabilization. This study uses POFA as a precursor, and alkali activators are sodium silica, $Na_2SiO_3$, and sodium hydroxide, NaOH. Measuring the chemical content of soil and POFA by XRF, observing the scanning microscopic samples (SEM), and conducting physical and mechanical testing. Physical tests were conducted to establish a model of subgrade layers on a laboratory scale. Deformation from the subgrade due to applied loading was determined by plate load test. Subsequently, the capacity of samples was determined by the laboratory CBR test. This study aims to evaluate the feasibility of soil-stabilized POFA-based alkali-activated material, focusing on deformation and capacity as a subgrade structure. Having a novelty on innovation the development of soil stabilization method to subgrade by adding the alkali activated POFA material in focus the strength and load-settlement. This study attempts to encourage the POFA material as a modern stabilization agent. We need to think critically to create a sustainable material that can diminish our dependency on cement while preserving effective performance. Therefore, it can diminish the consumption of cement in the future.

## 2 Materials

### 2.1 Soil

The soil was a disturbed sample collected from an excavating field to an embankment project in Pekanbaru City, Riau, Indonesia. The soil is then stored in the sack to keep its condition before testing in the laboratory. Preparing the soil sample by drying it in the sun for sieve analysis is easier and is useful for other soil properties tests. The characteristics and classified the soil sample can be seen in Table 1. Classified soil samples according to the USCS (Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Officials) methods.

Table 1: Soil properties test

| Parameter | Item | Values |
|---|---|---|
| Water content | [%] | 12.28 |
| Specific gravity, Gs | - | 2.66 |
| Liquid limit, LL | [%] | 31.59 |
| Plastic limit, PL | [%] | 20.39 |
| Plasticity index, PI | [%] | 11.20 |
| Group Index, GI | - | 1.42 |
| Clay and silt | [%] | 5.12 |
| Sand | [%] | 94.88 |
| Uniformity Coefficient, Cu | - | 4.4 |
| Coefficient of Curvature, Cc | - | 1.2 |
| USCS classified | SP SC | Clayey sand poorly gradation |
| AASHTO classified | A-2-6 | Clayey sand |

Refer to the USCS method, the soil grains greater than 50% were retained in sieve no. 200 (75 μm), and greater than 50% were passed in sieve no. 4 (475 μm) can be classified into the symbols SW, SP, SM, and SC groups. The abbreviation of SW is Sand Well graded, SP is Sand Poorly graded, SM is Sand Silty, and SC is Sand Clayey. Furthermore, fine grains of sieve no. 200 of 5.12 % (5 – 12 % range) were passed into the double symbol of SW-SM or SP-SC classification limits. The $C_c$ value of 4.4 is less than 6 minimum, and the $C_u$ value of 1.2 is in the 1 – 3 range. Therefore, the value of $C_u$ < 6, the soil classified is Poorly graded. Subsequently, the index plasticity (PI) is 11.20% greater than the 7% minimum. Hence, the soil can be classified as a symbol of the SP-SC group (clayey sand, poor gradation). Subsequently, referring to the AASHTO method, the soil grains of 5.12% passed sieve no. 200, less than 35% maximum, and have a liquid limit (LL) of 31.59, less than 40% maximum, and plasticity index (PI) of 11.20% greater than 11% minimum with group index (GI) of 1.42 less than 4 maximum. Therefore, it can be classified in the A-2-6 group (clayey sand) in good criteria as subgrade.

The chemical composition of the soil sample was obtained using X-ray fluorescence (XRF) to identify the percentage of chemical content, which can be seen in Table 2.

### 2.2 POFA (Palm Oil Fuel Ash)

The POFA was collected from a palm oil mill in Pelalawan Regency, Riau, Indonesia, and is still in the raw material category. To mix into the soil better, treatment by refining the raw POFA under grinding is possible. The difference in the grain size between soil, raw POFA, and treated POFA can be seen in Fig. 2. This Shows the effect of grinding on POFA, and the gained grain size is smaller than raw POFA.

Subsequently, the raw POFA was reburn at ± 250°C for 24 hours in a furnace to enhance the requirement of chemical quality classified and diminish the carbon. This treatment refers to a previous study from Alsubari et.al, 2018, regarding the burning way with high temperature in an electrical furnace to obtain better pozzolan [13]. Examine the chemical composition the raw POFA, treated POFA and soil with an XRF (X-ray Fluorescence) test. The all chemical composition results can be seen in Table 2. The burning procces affected to alteration the POFA quality by enhancing the chemical composition requirements from 46.12% to 65.43%. Mentioned with exhibit the change in classification from C to F and shows the POFA having good quality. According to ASTM C 618-19 is related the chemical requirements for pozzolanic properties regarding the combination of silicon dioxide, alumina oxide and iron oxide [25]. The raw POFA is classified as class C because it does not have the alumina oxide, and it fails to meet the composition requirements of less than 50% minimum. Instead, the treated POFA meets the applicable requirements for class F with its combination of more than 50% minimum. The presence of the alumina oxide and acceptable chemical composition are in better quality indication. Treated POFA was chosen as a precursor to incorporation into the soil, and next, its called POFA.

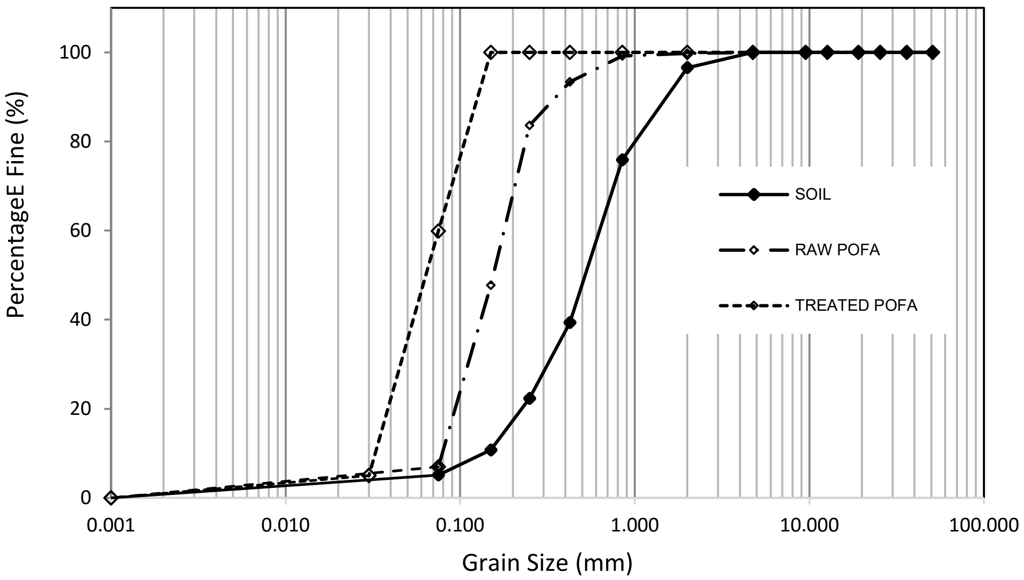


Fig. 2: Particle size distribution curve of soil and POFA

Table 2: Chemical composition of POFA and soil

| Composition | Item | Content | | |
|---|---|---|---|---|
| | | Raw POFA | Treated POFA | Soil |
| Silicon dioxide, SiO2 | % | 39.88 | 55.36 | 61.32 |
| Alumina oxide, Al2O3 | % | - | 3.64 | 24.50 |
| Iron oxide, Fe2O3 | % | 6.24 | 6.43 | 5.45 |
| Sulfur trioxide | % | 7.67 | 6.60 | - |
| CaO | % | 17.43 | 14.81 | 0.91 |
| Other | % | 28.79 | 19.77 | 7.82 |
| Chemical requirements according to ASTM C 618 ($SiO_2$+ $Al_2O_3$+ $Fe_2O_3$) | | 46.12 (class C) | 65.43 (class F) | |

## 2.3 Alkali Activator

The Sodium silica ($Na_2SiO_3$) and Sodium hydroxide (NaOH) as alkali activator was purchased at the chemical store. Both are activators in soil-POFA mixed and function for reacting chemical compounds (Silica and Alumina) in the POFA. Sodium silica or water glass is an aqueous solution prepared by fusing silicon dioxide ($SiO_2$) and sodium oxide ($Na_2O$). Constituent ingredients of sodium silica are 28% silica ($SiO_2$) + 9% sodium oxide (Na2O) + 63% water. Meanwhile, sodium hydroxide or caustic soda has a 98-99% purity level. White pellets form by fusing sodium (Na), oxygen (O), and hydrogen (H) atoms.

## 3 Methods

### 3.1 Compaction standard test

To obtain the optimum moisture content (OMC) and maximum dry density (MDD), a compaction standard test was conducted on soil and soil-POFA mixed. It means determining the OMC chosen for guidance on the solution content of alkali activator in soil-POFA mixed. The compaction standard test is according to the standard Proctor method (ASTM D 698-91). Five compaction samples were conducted in the mold for soil and soil-POFA mixed, respectively. Determining optimum moisture content with a curve shape that shows the effect added to the water content on samples can be seen in Fig.3.

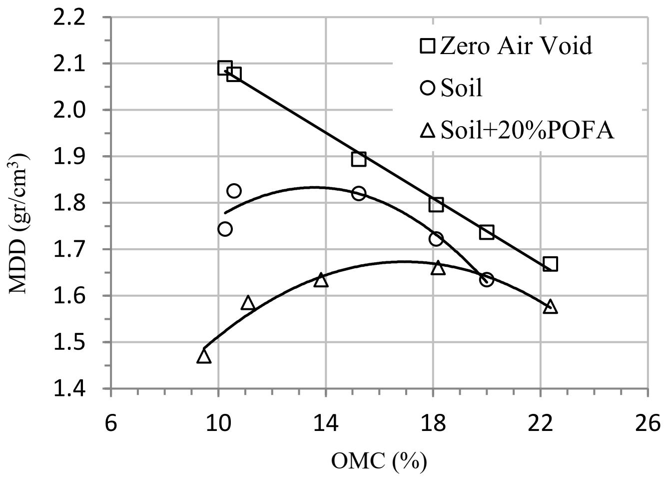


Fig. 3: Determining of optimum moisture content

Based on the curves in Fig. 3, attempts compacted test (Proctor standard) obtained the OMC and MDD in Table 4. An alkali activator solution in the soil mixture will replace the OMC of soil + 20% POFA mixed.

Table 4: Determining of the OMC and MDD

| Samples | OMC [%] | MDD [gr/cm$^3$] |
|---|---|---|
| Soil | 13.60 | 1.84 |
| Soil + 20% POFA | 17.00 | 1.68 |

### 3.2 Samples preparation

The Soil sample and POFA as precursors, as well as the sodium silica ($Na_2SiO_3$) and sodium hydroxide (NaOH), are subject materials. The POFA content added to the soil mixture was 20% of the weight of the soil. Effective POFA content in the range of 20-25% and sodium hydroxide on solution concentrate of 10M to improve the soil strength considering the economical and practice [16]. Sodium hydroxide solution was prepared in 1 litre soluble with concentrate of 10M molarity level for 24 hours. Furthermore, fusing the sodium silica/sodium hydroxide (Si/Al) of 2.5 ratio as a binder because it provides higher compressive strength [17,19].

The strength characteristic of the subgrade is measured using the CBR and plate load tests. Variations in the samples test consist of soil, soil + 20% POFA (soil-POFA), and soil + 20% POFA + Alkali activator (Si/Al) 2.5 ratio (soil-AAP). For the CBR test, according to ASTM D 1883-99, the curing of the sample was prepared for 4, 7, and 11 days in soaked condition for 96 hours after curing ages. Each sample was treated with plastic wrap to keep the chemical hydration process.

Subsequently, samples were prepared using a physical model of the subgrade layer in a box test. The height total of the subgrade is 65 cm. Divided into a support layer of 50 cm and a stabilized subgrade layer of 15 cm. Testing the subgrade layer was conducted thrice. First, to subgrade soil, second to soil + 20% POFA, and third to soil + 20% POFA + Alkali Activator in ratio (Si/Al) of 2.5. Mixturing the materials was performed manually until the admixture appeared homogenous. The subgrade layer model was then cured for 7 days before testing to process a synthesis of the aluminosilicate reaction, and the composition of the sample mixture is shown in Table 5.

Table 5: Composition of the soil stabilization mixture

| **Mixture** | **ID** | **Soil [gr]** | **POFA [gr]** | **Alkali Solution based OMC [gr]** | **$Na_2SiO_3$, Si [gr]** | **NaOH, Al Soluble [gr]** |
|---|---|---|---|---|---|---|
| Soil | Soil | 128,400 | - | - | - | - |
| Soil + 20% POFA | Soil-POFA | 102,720 | 25,680 | - | - | - |
| Soil + 20% POFA + AA 2.5 | Soil-AAP | 102,720 | 25,680 | 21,828.0 | 15,591.4 | 6,236.6 |

A set of equipment for the plate loading test, according to AASHTO T222-81, was prepared in the laboratory to support the achievement of this study. Consists of an equipped steel box with length, broad, and height dimensions of 80 cm x 80 cm x 80 cm, and one side is transparency glass. Be equipped with a steel girder to hold hydraulic jack forces with a capacity of 120 kN. Subsequently, three circular steel bearing plates thick of 2.54 cm, having diameters of 5 cm, 12 cm, and 20 cm, respectively, and two dial gauges on the plate in Fig 4.

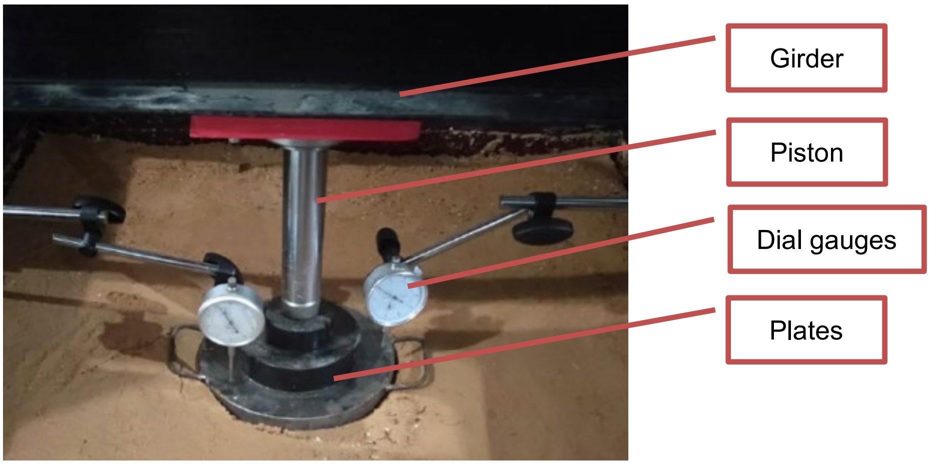


Fig. 4: Plate loading test equipment.

Loading was slowly applied at a speed not greater than 0.02 mm/min and kept for three consecutive minutes. Discontinue testing if a failure occurs on a sample or achieve the settlement of 25 mm as allowed. Equations from data plate loading test to gain modulus of subgrade reaction empiric ($k_{s1}$) as in:

$$k_{s1} = \frac{P/A}{\delta} \tag{1}$$

Where:
$k_{s1}$ - definition of modulus of subgrade reaction empiric,
$P$ - definition of load,
A - definition of the diameter of plate empiric,
Δ - definition of settlement.

The standard diameter of a bearing plate is 750 mm, whereas this study used 200 mm. Hence, correction is required with the equation as in:

$$k_{s1} = \frac{k_{s1}/a_1}{a} \tag{2}$$

Where:
$k_s$ - definition of modulus of subgrade reaction standard,
$k_{s1}$ - definition of modulus of subgrade reaction empiric,
$a_1$ - definition of the diameter of plate empiric,
$a$ - definition of the diameter of plate standard.

### 3.3 Microstructural test

Examine the microstructural of samples used a SEM equipment with the specification brand of JEOL JSM-6360LA. Aim to know the morphology of samples on a microstructure scale and measure the composition of the compound ingredients. Flake samples were formed, scanning was conducted on soil, and soil-AAP was mixed.

## 4 Results and Discussions

### 4.1 California Bearing Ratio (CBR) test

Incorporating POFA and alkali activator affects soil characteristics exhibited for curing ages [Fig. 5]. Alteration of the behavior CBR values in soaked conditions revealed the unstable consistency related to strength due to the water effect in the mixture.

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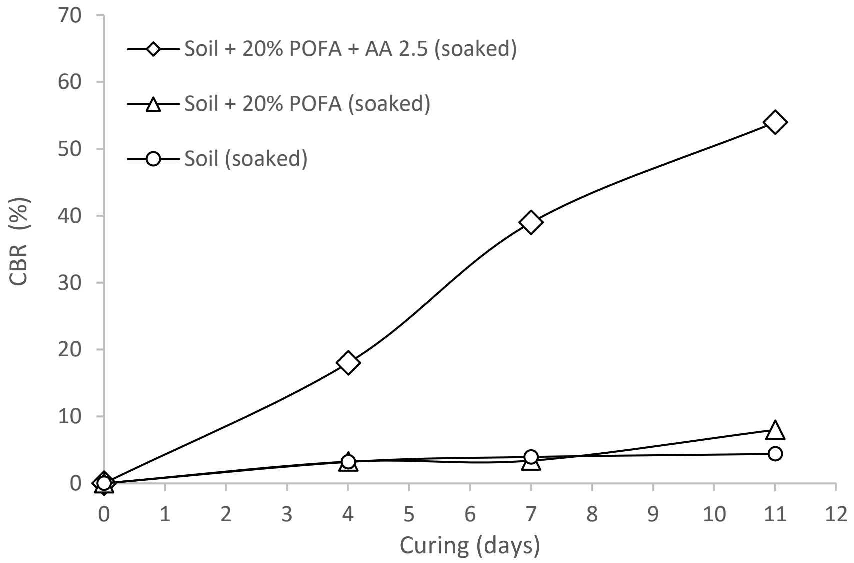



Fig. 5: CBR values on curing ages

The CBR values of soil did not show a significant increase in strength with curing ages. From curing ages 4, 7, and 11 days, the strength only slightly increased CBR 3.2% to 3.4 and 4.4%, respectively. It does not meet the requirement for a subgrade of 6% minimum. Adding POFA to the soil mixture exhibited an increase in strength. Proven for 11 days curing age, showed that 20% POFA in soil mixture can improve the CBR values up to 8%. The evaporation of water in a mixture for curing and the fine grain size of POFA has contributed to filling the void of soil pores and obtained an increase of CBR values almost two times that of soil only. Despite for 4 and 7 days, the soil-POFA showed a slight decrease in strength due to elevated moisture content.

Furthermore, soil stabilized with the incorporation of POFA and alkali activators that consist of sodium silica ($Na_2SiO_3$) and sodium hydroxide (NaOH) showed a significant increase in soil strength. The alkali activator solution content was added to 17% in soil-POFA mixed as optimum moisture content replacement. The curing measure needs to let chemical reactions in mixtures. The result shows that the performance of the soil + POFA + Alkali activator is exhibited from early curing for 4 days, and its strength increased almost 6 times to CBR 18%. Then, curing for 7 days, the strength increased by almost 10 times to CBR 39%, and for 11 days, it increased by 12 times to CBR 54%.

Incorporation of sodium silica and sodium hydroxide as binders in a soil-POFA mixture can improve the mechanism characteristic of poor soil. Previous studies also revealed that adding sodium silica and sodium hydroxide to soil-POFA mixed can increase the compression strength [17][26]. The curing measure has a chance to hydration processes of synthetic aluminosilicate in the crystalline phase. Changing the poor soil characteristics makes it dense, and the assessments of the subgrades are excellent and comply with technical requirements.

### 4.2 Deformation of Subgrades

Determining the deformation of subgrades by conducting the plate loading test series. As a hydraulic jack to loading, the piston is placed on the centre of the circular plates in a vertical direction. Then, the peak of the load is recorded if the subgrade layer achieves the maximum settlement of 25 mm or imminent failure. The performance of plate bearing tests on samples can be seen in Fig. 6 and 7. The deformation behaviour of subgrade layers is also described as incremental loading.

Fig. 6: A performance of the plate loading test on subgrade stabilized

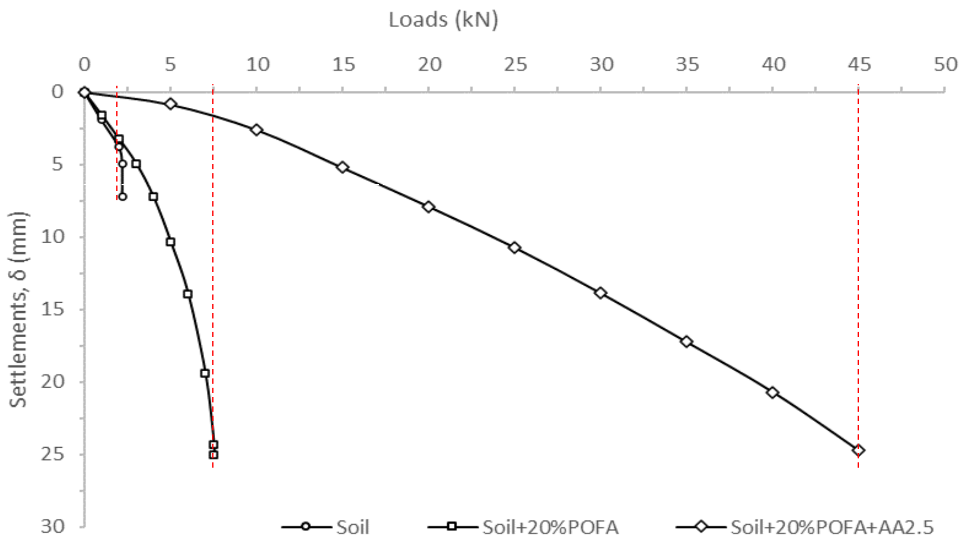



Fig. 7: The curve of loading to settlements.

The plate loading test to subgrade the soil layer shows a lower capacity with failure on initial loading. In the first stage, the soil layer was applied to 1.0 KN, and a settlement of 1.95 mm was obtained. Subsequently, incremental loading continued when applied to 2.0 KN and gained the settlement of 3.77 mm. After that, the incremental loading continued to 3 KN but stopped at 2.2 KN due to no incremental loading occurring and its settlement of 7.21 mm. This indicates the soil layer has failed before achieving peak loading.

Furthermore, soil + 20% POFA (soil-POFA) obtained a slight increase in the bearing capacity of the subgrade. Applying an equal load of 2.0 KN shows a decreased settlement to 3.21 mm from 3.77 mm previously. Next, the load was applied every 1.0 KN and increments per 30 seconds were recorded. Subsequently, due to the imminent settlement of a maximum of 25.0 mm, the loading stopped at a peak of 7.5 KN.

Meanwhile, soil + 20% POFA + Alkali activator (soil-AAP) applied an equal load of 2.0 KN and did not affect settlement behaviour. This means that the alkali activator, as a binder, is important in interlocking soil-POFA mixtures. The initial alteration of the deformation occurred to increment the vertical load by 5.0 KN, with the settlement only of 0.86 mm. Revealed stabilization soil-AAP can reduce settlements with an equal load applied. Furthermore, the testing is continuous, with incremental loading every 5 KN until the settlement is allowed. Hence, the peak load of 45.0 KN is larger than that of the soil and soil-POFA subgrade layers.

Results of the performance of the subgrade layer by plate load test can be seen in Table 6. Subsequently, Tabel 7 shows correction of the modulus of subgrade reaction ($k_s$) in referring to equations (1) and (2) for the standard plate in the contact area to the surface. Subgrades of soil and soil-POFA mixed layers have a close value to the modulus of subgrade reaction. Meanwhile, soil-AAP mixed has a higher value, which indicates that soil stabilizes, and AAP enhances soil strength. The incorporation of sodium silica and sodium hydroxide has a significant effect on improving the strength and stiffness [27].

Besides, relations between loading and settlement can lead to the prediction of the bearing capacity of subgrades. The result of the performance plate load test shows that the subgrade to the soil layer has a bearing capacity of 2.2 KN, and the testing was stopped because the increment loading did not occur, and the subgrade had a failure condition. The soil-POFA mixed has a failure condition on loading 7.5 KN as the bearing capacity. Furthermore, the subgrade to soil-AAP mixed has a bearing capacity of 45 KN, with the decision being a larger bearing capacity.

Analysis of the modulus of subgrade reaction is determined by the contact area between plate to subgrade surface based on a standard plate of 750 mm. Hence, the modulus of subgrade reaction between soil and soil-POFA have close values of 4.35 and 4.80 kPa/mm respectively. Meanwhile, the soil-AAP obtained a higher value of 49.64 kPa/mm. Having the modulus of subgrade reaction values greater than others can indicate the resistance of the subgrade layer toward incremental loading is already better with minimum deformation.

Table 6: Relationship between the loading and settlement

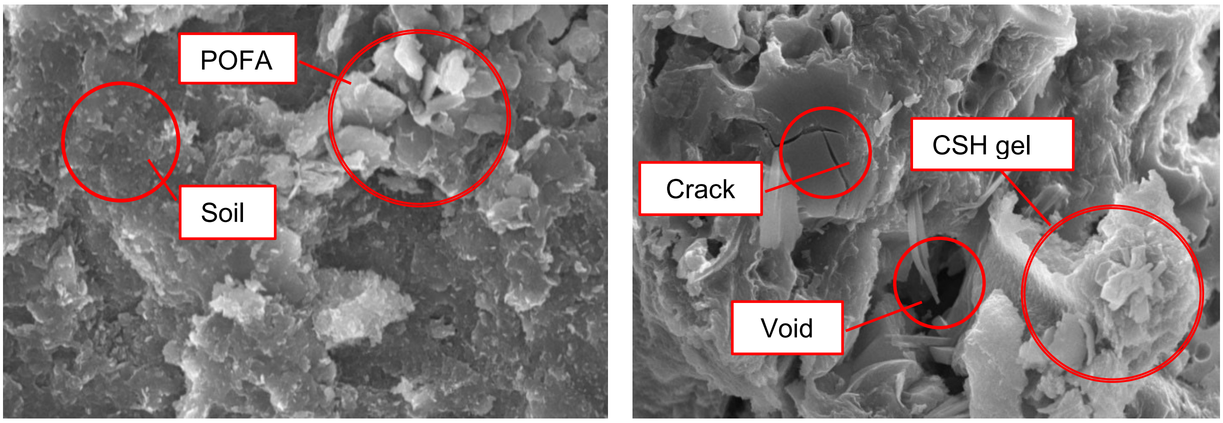
| **Mixture** | **Loads [kN]** | **Settlement [mm]** |
|---|---|---|
| Soil | 2.20 | 7.21 |
| Soil-POFA | 7.50 | 24.31 |
| Soil-AAP | 45.00 | 24.75 |

Table 7: Correction of the modulus of subgrade reaction

| **Mixture** | **Empiric $k_{s1}$ [kPa/mm]** | **Standard $k_s$ [kPa/mm]** |
|---|---|---|
| Soil | 16.32 | 4.35 |
| Soil-POFA | 17.98 | 4.80 |
| Soil-AAP | 186.15 | 49.64 |

### 4.3 Morphological analysis by SEM

Morphology observation by SEM (Scanning Electron Microscopic) test with the brand specification of JEOL JSM-6360LA. Solid samples consist of soil, soil-POFA mixed, and soil-AAP mixed and prepared before testing. The result of morphology observation can be seen in Fig. 8 with magnifying 3000x. The morphology of soil shows the solid form in fine grains. Meanwhile, the POFA shows that lamellar sheets coincide [Fig.8a]. Furthermore, the morphology of soil-AAP mixed shows the bonding synthetic of aluminosilicate as C-S-H (Calcium-Silicate-Hydrate) gel that does not perfectly disperse due to still having voids in the matrix structure [Fig.8b]. Mechanism the pozzolanic reaction of POFA in a soil mixture that establishes the formation of calcium and silica elements and then produces a reaction of calcium silica hydrate (C-S-H) form [24-25]. The crack is found in a matrix structure close to voids, and the object appears dim, indicating poor bonding. The chemical reaction of soil-AAP mixture through three phases is dissolving silicate-alumina, initially setting the silica-alumina bonding structure, and hardening to be a polymer structure [30].




[a] Soil-POFA [b] Soil-POFA mixed

Fig. 8: Morphology observation by SEM

### 5 Conclusion

Based on the discussion, evaluate of the feasibility of soil-AAP stabilization can be concluded to answer the research objectives. Incorporation of the sodium silica and sodium hydroxide into a soil-POFA mixture can significantly increase the CBR value at 11 days of curing by 54%. Stabilization of soil-AAP mixture can diminish deformation and increase the bearing capacity of the subgrade with a maximum load of 45 kN. The morphology observation from SEM analysis showed the bonding synthetic of aluminosilicate form in the C-S-H gels.

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