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PALM OIL FUEL ASH (POFA) AS AGRO-WASTE TO MODERN STABILIZATION ON SUBGRADE

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Abstract: *Subgrades in low bearing capacity are often improved by traditional stabilization methods using cement and lime, that have problems with environmental issues. Because processes cement production released Carbondioxide (CO_2) to the atmosfer. Instead, required modern stabilization methods utilizing environmentally friendly materials, such as POFA from agro-waste, are known. The purpose of the research is to obtain the strength of soil by adding 20% POFA. Methods used for this study are conduct soil properties test, examine the chemical compositions of POFA by X-Ray Fluorescene (XRF), CBRsoaked tests and Scanning Electron Microscopic (SEM) observation. The physical properties test has found the soil classificated as SP-SC (poor gradation clay sand). Affect of added 20% POFA able to changes consistency limits of soil by reduce the plasticity index (PI) of 11.20% to 3.63% or medium to low plasticity. Chemical compositions of POFA has high the Silica (Si) content of 55.36%. Treated POFA able to produce the fine grains than raw POFA and soil. Then occured decreasing of MDD from 1.83 to 1.68 gr/cm^3 and increasing of OMC from 13.60% to 17.0%. The CBRsoaked test obtained the strength of soil-POFA stabilization until curing of 7 days to exhibited an increasing CBR value of 3.25% to 8%. It was comply to CBR value standard for subgrades of 6% minimum, according in Indonesia Ministry of Public Works and Public Housing about General Spesifications of Bina Marga (revised 2). Microscopic observations through SEM analysis revealed that POFA material helped to fill soil pores and resulting a denser soil structure. Hence, the POFA is feasible for exhibited as alternative modern stabilization material.*

Keywords : *CBR, Microscopic, POFA, Stabilization, Strength, Subgrade.*

Abstrak: Tanah dasar yang memiliki kuat dukung rendah sering mendapat perlakuan perbaikan properties menggunakan metode stabilisasi tanah cara tradisional dengan menambahkan semen dan kapur. Cara ini memiliki masalah dengan isu lingkungan karena proses produksi bahan semen melepaskan karbondioksiada ke udara. Sebaliknya metode stabilisasi modern dikenal ramah lingkungan seperti POFA dari limbah perkebunan pabrik kelapa sawit. Tujuan penelitian untuk mendapatkan kekuatan tanah dengan menambahkan 20% POFA. Pengukuran benda uji terdiri dari uji properties, uji XRF (*X-Ray Fluorescence*) untuk pemeriksaan kandungan mineral POFA, uji CBRrendaman dan pengamatan mikroskopik (SEM) permukaan benda uji. Hasil uji properties mendapatkan tanah masuk kedalam golongan SP-SC (pasir berlempung gradasi buruk). Pengaruh tambahan 20% POFA untuk tanah mampu mengurangi indeks plastisitas dari 11.20% menjadi 3.63% atau dari plastisitas sedang menjadi rendah. Pemeriksaan komposisi kimia POFA diketahui memiliki kandungan kaya Silika (*Si*) sebesar 55.36%. POFA yang dirawat menghasilkan butiran yang lebih halus dari POFA mentah dan tanah. Terjadi penurunan MDD dari 1.83 gr/cm^3 menjadi 1.68 gr/cm^3 dan peningkatan OMC dari 13.60% menjadi 17.0%. Selanjutnya hasil uji CBRrendaman mendapatkan peningkatan kekuatan tanah sampai pemeraman 7 hari yang ditunjukkan dengan nilai CBR dari 3.25% menjadi 8%. Peningkatan ini sudah memenuhi nilai CBR standar minimum 6% untuk lapisan tanah dasar berdasarkan Spesifikasi Umum Bina Marga (revisi 2) dari Kementerian Umum dan Perumahan Rakyat Indonesia.

Pengamatan mikroskopik (SEM) menunjukkan bahwa penyertaan POFA dapat membantu mengisi pori-pori tanah dan menghasilkan struktur tanah menjadi lebih padat. Oleh karena itu POFA layak untuk diajukan sebagai alternatif bahan stabilisasi tanah cara modern.

Kata kunci : CBR, Mikroskopik, POFA, Stabilisasi, Kekuatan, Tanah dasar.

1. INTRODUCTION

Stabilization for subgrade with adding cement and lime have to reduced by finding other alternative stabilization materials that more environmentally-friendly. The cement has environmental issues because almost ≈ 1 ton of carbon dioxide emissions (CO_2) released into the atmosfer is equivalent to the production of 1 ton of cement [1]. Agro-waste from palm oil mills such as POFA can be used as an alternative to other stabilization materials as substitute of cement and lime for subgrade. Utilizing industrial waste for soil stabilization is the best way to reduce the negative effects of the waste [2].

Recently, utilizing waste materials for subgrade stabilization has been environmentally-friendly and low-cost [3]. The largest oil palm plantation in the world is Indonesia and source data of production until 2019 reached more than 45 million tons and the total area of palm oil plantation recorded at more than 14 million hectares [4]. The process of cultivate palm oil that produces CPO (Crude Palm Oil). Its has an impact on the amount of agro-waste disposed to the field and is not utilized optimally. Therefore, it has potential to generate any damage for environment and health.

In the process of produce palm oil, can be estimated to generate total amount of solid waste from fresh fruit bunches of 35-40% [5]. Subsequently the process of produce palm oil, also generate of liquid and gas wastes. Derivative of the solid waste is Palm Oil Fuel Ash (POFA) that compound of shells, empty fruit bunches and fibers. They were burned at a temperature of 800-1000°C as fuel to provide hot steam for power plants (boiler) at palm oil mills. Furthermore, through combustion process that obtained the ash material, which is about 5% of the weight is known as POFA [6].

Subsequently, POFA can be classified into synthetic pozzolan that have mineral composition of silica and alumina elements [7]. Silica and alumina content in the fine POFA and when be reacted with calcium hydroxide can harden like cement [8]. Treatment of POFA through grinding and burning can reduce carbon levels and also improve its mineral composition [9].

Thereby, presence of POFA in the soil mixture can lead to a positive influence on physical and mechanical properties. Adding POFA in the mix design on ranges of 10-20% of dry weight soil, was obtained the maximum strength results [10] [11]. The plasticity index decrease and the CBR value increase when added of POFA from 10 - 18% to clay soil stabilization [12].

The fine particle of POFA can be distributed thoroughly filling the pores of soil and providing a locking effect between grains and finally increase the shear strength of the soil [13]. Soil density also increase along with added quantity of POFA contents from 10% – 15% [14]. Adding POFA in soil-cement mixture results in higher compressive strength rather than without POFA [15]. Soil stabilization with adding 14% POFA provide the strength for subgrade construction and suitable for landfill sites [16]. POFA that added to soil-lime mixture and provide affects increasing the value of CBRsoaked and unsoaked on the subgrade [17]. The POFA material can be shown in **Figure 1**.

Figure 1. POFA disposed beside the boiler unit

The objective of this study is to evaluate the impact of incorporating 20% Palm Oil Fuel Ash (POFA) into soil, focusing on alterations in soil characteristics, enhancement of strength, and changes observable through Scanning Electron Microscopy (SEM). This research attempts to promote the use of POFA as a modern stabilizing agent. At present, there is a critical need to create sustainable materials that can diminish our dependence on cement while maintaining effective performance. Furthermore, having chance to reduce consumption of cement and lime in the future.

2. METHODS

The research stages consist of properties and mechanical tests and microscopic observations on surface the samples. Both of soil and POFA were taken using shovel and stored in the sack. Furthermore, they were be carried to laboratory for preparing before testing. Soil was dried in the sun to obtain dry conditions. Soil that still have shape of lumps was crushed using rubber hammer to obtain be smaller grains. After that soil then be prepared for properties and mechanical test.

The POFA taken from palm oil mill and be carried to laboratory too. POFA have to cleaned from dirt and ensure that contain of fine grains. POFA be taken out from sack and then refined using grinding machine. Subsequently, POFA sieved to obtain fine grains of measure less than 150 µm using sieves no.100 and 200. Then POFA treated by burning in a furnace at 250° C for ± 7 hours. Better pozzolan quality can be improved by re-burned of POFA in high temperatures [18]. Burning and refined of POFA is able to diminish carbon content and enhance chemical compound [9].

Properties test is conducted to obtain the classifications of soil. Consists of moisture content test, grain analysis, consistency limits test, specific gravity test and volumetric weight test. Methods for soil classification is according the USCS (Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Officials). Consistency test of soil added 20% POFA also conducted to get how much effect for alteration in plasticity index. Furthermore, the chemical composition of POFA be examined by XRF (X-ray fluorescence).

Subsequently, conducting the mechanical tests are consist of standard Proctor and CBRsoaked. The CBR test on immersion condition with curing of 0; 3; 7 days. Then the CBR test procedure is according to SNI 1744: 2012. While optimum moisture content (OMC) added to the CBR samples based on the results of standard Proctor test. After that, observe the surface soil samples in terms condition before and after added 20% POFA using SEM (Scanning Electron Microscopic). It is a research tool to examined, diagnosis and understand basic different performance of soil types in various condition from microscopic surface observation [19].

3. RESULTS AND DISCUSSIONS

Classification of Soil

The results of physical properties of soil test can be seen in **Table 1**.

Table 1. Physical properties of soil sample

Parameters	Results
Water content	12.28%
Specific gravity (Gs)	2.66
Liquid limit	31.59%
Plastic limit	20.39%
Plasticity index	11.20%
Clay and silt	5.12%
Sand	94.88%
Uniformity Coefficient, C_u	4.4
Coefficient of Curvature,C_c	1.2

Table 1 shown the physical properties of soil that can determine the classification of soil type. Water content of 12.28% and it found the soil has low water content as typical of sand. Which, ranges of moisture content in sand types is 32% maximum [20]. Then, specific gravity of 2.66 is classified the sand or silty group [21].

According the USCS method, soil with 50% or more retained filter no. 200 (0.075 mm) and 50% or more passed filter no. 4 (4.75 mm). Soil can be classificated into the symbols SW, SP, SM, SC. Understanding to SW as Sand Well graded, SP as Sand Poorly graded, SM as Sand Silty and SC as Sand Clayey. Subsequently, fine grains that passed filter no. 200 of 5.12 % and it is in ranges of 5 – 12 %. Thereby, soil has double symbol classification of SW-SM or SP-SC. Both are them will be defined by C_u and C_c rate. **Figure 2** shown the uniformity Coefficient (C_u) and the Coefficient of curvature (C_c). The calculated of C_c by ratio grains size diameter of 60% passed to diameter 10% passed of 4.4 < 6 minimum, are known. Whereas for C_c is parameter to indicating of the grains size distribution curve, with result of 1.2 and it is in range 1 – 3, are known. Because C_u < 6 minimum, thus soil classified as Poorly graded. Then, index plasticity (PI) the soil of 11.20% > 7 minimum, are known. The Finally the soil can be classified into the symbol the SP-SC group (clayey sand poorly gradation).

According to the AASHTO method, the soil sample, with 5.12% passing through sieve No. 200 (less than the 35% maximum) and having a liquid limit (LL) of 31.59 (below the 40% maximum) and a plasticity index (PI) of 11.20% (exceeding the 11% minimum), is classified within the A-2-6 group (silty or clayey sand).

Characteristics of POFA

Sieves no. 100 (150 µm) and no. 200 (75 µm) were used to distribution grains size of raw and treated POFA. The results of sieves analysis of POFA and soil can be seen in **Figure 2**.

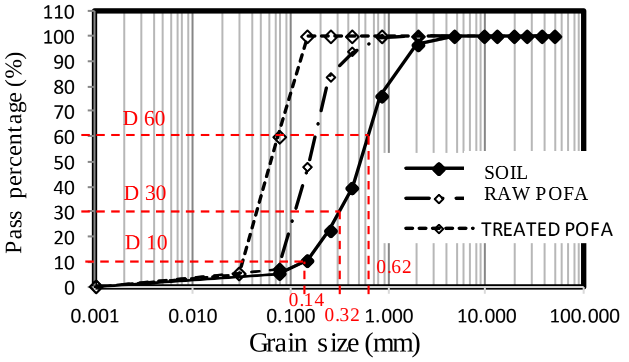

Figure. 2. Sieves analysis of soil, raw and treated POFA

Figure 2 shown that the POFA has smaller grains size percentage than soil. However, raw POFA has grains size of 0.150 – 2.00 mm and that it could not comply to filling the pores of soil. Hence, preference to treatment of POFA through a grinding machine to refine the coarse grains. The result obtained was treated POFA more smaller grains than raw POFA. Treated POFA have grains size less than 150 µm and better than before.

Chemicals composition of POFA known based on the XRF (X-Ray Fluorescence) test and can be seen in **Table 2**.

Table 2. Chemical composition of POFA

Composition	Content (%)
SiO_2	55.36
Al_2O_3	3.64
Fe_2O_3	6.43
CaO	14.81
SO_3	6.60
Other	19.77

Based on ASTM C618, classification for ash requirement in class F and class C. From **Table 2**, sum of chemicals composition content of SiO_2 + Al_2O_3 + Fe_2O_3 were 65.43%. That value was greater than requirement of 50% and CaO value of less than 18%, thus POFA was classificated of class F [22].

Consistency Limits

The consistency limits that occured in the soil before and after mixing with POFA was affected by added moisture content in the samples.

POFA content affect in consistency limits of soil on Atterberg limits (liquid limit, plastic limit and plasticity index). Using the Cassagrande method to obtain this Atterberg limits. From the **Figure 3**, the liquid limit (LL) of soil was decrease after added 20% POFA, by 31.59% to 25.97%. Whereas the plastic limit (PL) was increase. Which percentage of water content previously 20.39% to 22.34%. Lead the soil plasticity index (PI) decrease of 11.20% to 3.63%. Thus, affect the added of 20% POFA in to the soil was able to changes soil properties from medium plasticity to low plasticity [21]. The effect elevate of POFA content of 5% - 40% lead decrease to index plasticity [23].

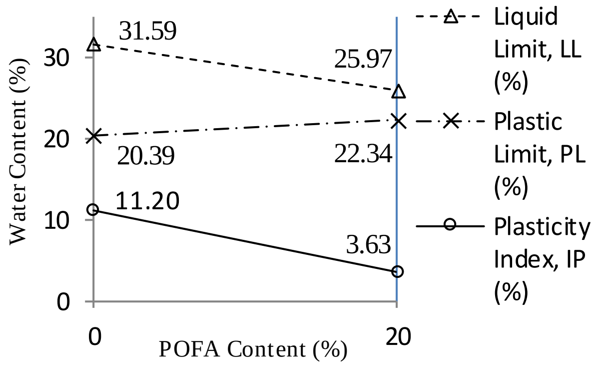

Figure 3. Consistency limits of soil-POFA mixed

Compaction Standard

The relation between OMC (Optimum Moisture Content) and MDD (Maximum Dry Density) on the samples is determined based on standard Proctor test. Procedure to occur the compaction test in laboratory is according of SNI 1742:2008. Preparing attempt to five samples testing approximately than dividen for soil and POFA mixed. The result can be seen in **Figure 4**.

Figure 4. shows mechanics properties of soil affected POFA material. The evidence seems to increasing the Optimum Moisture Content (OMC) of 13.60% to 17.0% and decreasing the Maximum Dry Density (MDD) of 1.83 gr/cm^3 to 1.68 gr/cm^3 after soil added 20% POFA. Decreasing the MDD and increasing OMC were indicated that POFA provide affect to behavior of soil mechanical properties. Hence, behavior of soil lead alteration to slight soft because the fine grains the POFA less than 150 µm caused absorption excess water in mixture.

Increasing OMC and decreasing MDD occured due to added POFA as soil stabilization materials [12][24][25]. The decrease in MDD with inclusion of POFA content is refer to the initial simultaneous flocculation and agglomeration of clay particles due to cation exchange capacity lead to increase in volume and decrease in dry density [25].

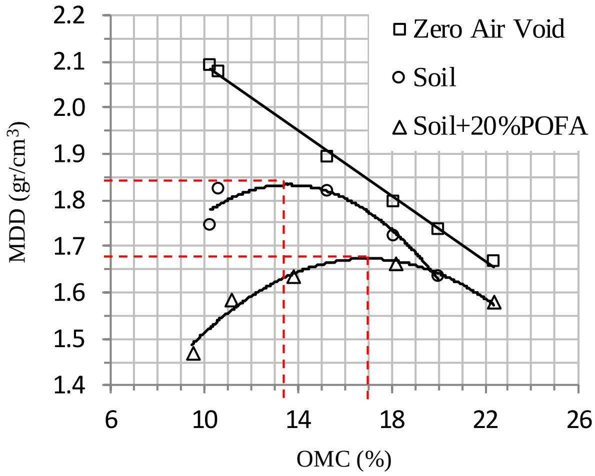

Figure. 4. Relation between MDD and OMC

California Bearing Ratio (CBR) test

The CBR test conducted to determine CBR value and the effects by add 20% POFA for soil stabilization. Soaked condition was chosen to measuring the CBR value in order to the samples assumed on bad condition. Samples cured for 0; 3 and 7 days in storage cabinet at ambience temperature. Each sample if reached curing ages, then the samples continue to immersion condition for 4 days into a container filled water. Process curing the samples in immersion condition must be safety from shaking and seem like in **Figure 5**.

Figure. 5. Soaked condition the samples

The relations between CBR design based on curing ages can be appear in **Figure 6**.

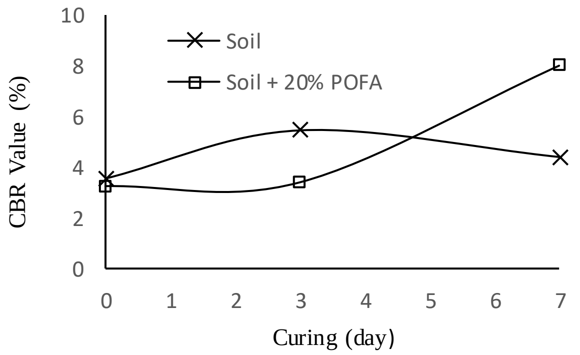

Figure 6. CBR value-based on curing ages

Figure 6 shown that ancient of curing provide the good performance toward increasing the CBR value. The CBR value of soil increased at 3 days, but occurred slight decrease at 7 days for the control soil, whereas it continued to increase for the soil-POFA mixed. Decreasing in CBR value of soil caused excess water pores while treatment on immersed condition for 4 days.

Proven to added 20% POFA could provide increasing of 3 to 7 days of CBR value that yield of 3.40% to 8% approximately. Increasing the CBR values of soil-POFA mixed is greater than the soil without POFA. Curing for 7 days in soil-POFA mixed affected on reaction process the POFA chemical compounds for soil to be denser. The results indicated that added POFA is able to increase the CBR value and decrease the swelling of soft soils [26]. Inclusion the POFA into soil lead enhancement CBR value of 5 times for curing 28 days when comparing to untreated soil [27].

Scanning Electron Microscopic (SEM)

Figure 7 and **Figure 8** these below shows the SEM observations for soils and soil-POFA mixed. The observations to samples utilized of SEM-EDS test equipment by brand JEOL JSM-6360LA specifications are intended to determine the morphological conditions of microscopic-scale.

Figure 7 and **Figure 8** shows the morphology of the specimens from the soil and soil-POFA mixed with a magnification of 10,000x. The morphology of the soil (**Figure 7**) appears the soil surface in undense grains structure seen undense and much large pores. Subsequently, morphology of the soil-POFA mixture (**Figure 8**) appears the surface shape seen dense grains structure and much smaller pores. Whereas, soil-POFA mixed could be identified in a shape of flat sheets which interlock together. The Soil-POFA mixed is exhibits the flocculated structure in very dense packing [28].

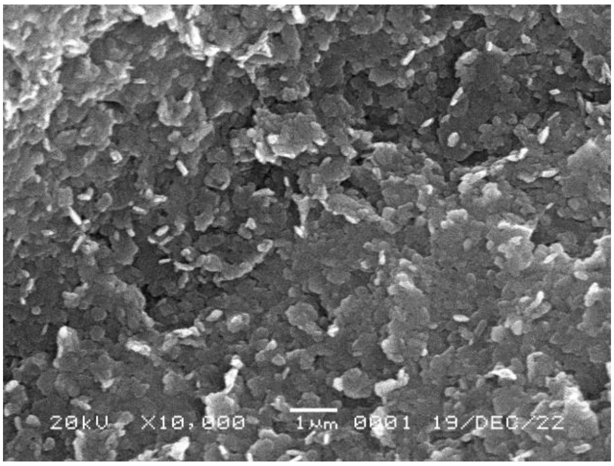

Figure 7. Microscopic image the Soil without POFA

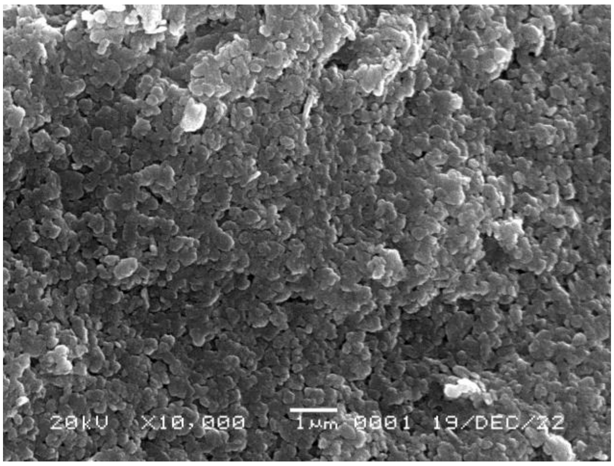

Figure 8. Microscopic image the Soil with POFA

4. CONCLUSIONS AND RECOMENDATIONS

Conclussions

Based on physical properties test obtained classification the soil is clayey sand poorly gradation with medium plasticity. Soil stabilization to added 20% POFA able to reduce plasticity index, PI from 11.20% to 3.63% and to be low plasticity criteria. Then occured decrease MDD of 1.83 gr/cm^3 to 1.68 gr/cm^3 and increase OMC of 13.60% to 17.0%. Adding 20% POFA to soil stabilized able to increase CBR value of 8% more than 6% minimum requirement for subgrade (according of General Specification of Bina Marga, revised 2). Subsequently, the SEM analysis revealed that POFA inclusion helped to fill soil pores and resulting in a denser soil structure. Hence, the POFA is feasible for exhibited as modern stabilization material.

Recomendation

The next study for soil stabilization could continued about optimally quality of POFA material through treatment methods as burning high temperature (500° C – 1000° C) and grinding to obtain the refine grains less than 75 µm.

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