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Performance of Soft Soil Stabilized by Fly Ash with Natural Fiber Reinforcement as Landfill Cover Layer

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Abstract - The use of clay as a landfill cover system is a choice of alternative materials that are widely used in almost all the existing landfill system in Indonesia and in the world. In addition to the relatively low cost of procurement is also available in almost all regions in Indonesia. However, alternative reliable overburden landfills has not been much discussed and researched. The purpose of this study is to design an ideal final cover layer landfill technically and mechanically. The results showed that the addition of fly ash and palm oil fiber (POF) between 10% of fly ash and 0.5% of POF can enhance the mechanical value of soils. the compressive strength of soils increase from 39.4 kPa to 89.0 kPa or rose by 129%, decreasing the value of soil hydraulic conductivity is to be 1.2×10^{-7} from the initial value of 1.17×10^{-6} or decreased by 850.4%, increase in soil friction angle of 8.55° to 24° , and lowering the soil liquid limit of 33.48% to 24.5%, decreasing of swelling potential of 8% to only 1.5% at the end of the wetting cycle, reduce the cracking intensity factor (CIF) from 1.96% to zero cracks. Mechanical behavior is heavily influenced by the nature of fly ash which has of a small water absorption and change the water in the soil for the pozzolanic reaction and produce calcium hydrate silica (CSH), in which the reaction is to form granules (binder) in the soil so that the soil becomes dense and hard, while palm oil fiber have cellulose and lignin as dominant compounds that tend to have high water absorption but serves to strengthen the fiber tensile force between the fibers and the soils surface due to adhesion forces so that the soil is not easily collapse and reduce the potential shrinkages and cracking of the soils..

Keywords: natural fibers fly ash, clay, landfill, crack, hydraulic conductivity.

I. INTRODUCTION

Cracks behavior of natural clay used as compacted clay liners (CCL) is the main problem of the structure of clay. because it will lead to cracks in the overburden landfills, and consequently will reduce the sealing function of the cover layer dramatically. From the standpoint of engineering, landfill cover materials must have sufficient technical properties, such as low hydraulic conductivity, sufficient compressive strength, high tensile strength, and flexibility. The drying process will lead to the behavior of cracks in clay soil will cause the surface of the liquid migrating into landfills causing increased liquid and gaseous waste. In the end the potential for contamination of soil and ground water will increase [14].

Currently there are several possibilities in the use of other materials to improve the performance of the clay as a hydraulic barrier in landfills. Research to design a cover liners that is ideal in landfills, which is to analyze the mechanical behavior of soft soil, the behavior and development of shrinkage and cracking of soft soil, stabilized fly ash and reinforcement fibers whether it can increase the capacity of soft soils as final cover landfill, it also makes models of laboratory hydraulic conductivity of soil stabilization fly ash and fiber in its effectiveness to retain surface run on and leachate from the landfill.

II. MATERIAL AND METHODS

A. MATERIALS USED.

Kalukubula clay soil is taken from south area of Palu City Central Celebes, while the fly ash is taken from coal combustion in steam power plant in north area of Palu City.

The Palm oil fibers is taken from Crude Palm Oil Company PT. Pasangkayu at North Mamuju distric. the fibers extracted by retting process (Figure 1). Fiber cut to the required length from 15mm to be mixed with the soil and fly ash.



Figure 1 (a) Palm Oil Fruit, (b) Palm oil fiber

B) LABORATORY EQUIPMENT.

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Tensile testing machine universal Instron 3367, Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS), The X-ray Diffraction (XRD), Moulds specimen, Standard Proctor test, Direct Shear test, Sieve Analysis test, Hydrometer test, Atterberg test, Compression unconfined test, Model of swelling and cracking potential test and hydraulic conductivity model test

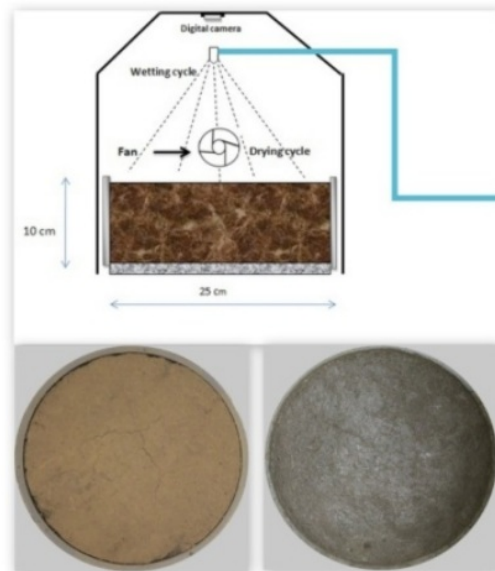


Figure 2 Model Of Swelling and Cracking Potential Test

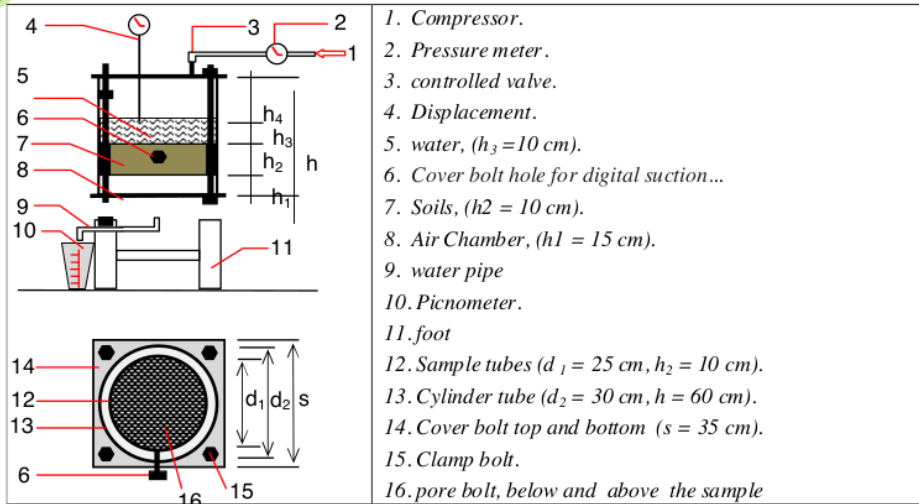


Figure 3 Model of Unsaturated Hydraulic Conductivity Pressurimeter Test

III. RESULTS AND DISCUSSION

SOILS PROPERTIES

The soil classification according to USCS is clay with low plasticity. Soils properties in laboratory testing conducted to obtain the physical and mechanical properties of the soil result: Specific Gravity (G_s) = 2,68 (ASTM D-854-92); liquid limit (LL) = 33,48%; plastic limit (PL) = 19,51%; plasticity index (PI) = 13,97% (ASTM D-4318-95); grain size distribution (ASTM D-422-93) be obtained: sand = 48,4%; silty = 32,6%; clay = 19%. Proctor standard test (ASTM D-1557-91) obtained maximum dry density ($\gamma_{dry\ max}$) 1,97 kN/m³ and the optimum water content (wopt) 11,10%. Chemical composition: Si O₂ = 67%, Fe₃ O₄ = 1,5%, Fe₂ O₃ = 2,2%, Ti O₂ = 2,4%, Na (Al Si₃ O₈) = 17%, and Ca (Al₂ Si₂ O₈) = 10,0%. Based on ASTM C618-92a 9 (ASTM 2008) which SiO₂ + Al₂O₃ + Fe₂O₃ = 68,9% less than 70%. Based on the above characteristics, then the physical properties and chemical compound content of soils test results for this study indicate that soils itself have pozzolanic materials.

FLY ASH PROPERTIES

Fly ash properties in laboratory testing conducted to obtain the physical and mechanical properties of the soil result: Specific Gravity (G_s) = 2,36 (ASTM D-854-92); plasticity = non plastic. Proctor standart tes (ASTM D-1557-91) obtained maximum dry density ($\gamma_{dry\ max}$) 1,52 kN/m³ and the optimum water content (wopt) 20,0%. Chemical composition: Si O₂ = 62%, Ca O₂ = 4,7%, Al₂ Si_{0.6} O_{4.8} = 19%, Mg Si O₃ = 7%, (Fe₂ Mg) O₄ = 3,7% and Fe₃ O₄ = 3,1%. Based on ASTM C618-92a 9 (ASTM 2008) which SiO₂ + Al₂O₃ + Fe₂O₃ = 85,8% with $\geq 70\%$. Based on the above characteristics, then the physical properties and chemical compound content of fly ash test results for this study indicate well as pozzolanic materials.

FIBER PROPERTIES

The properties of fiber are diameter (mm) = 0,20-0,50, density (g/mm³) = 0,7-1,55, tensile strength (Mpa) = 24,52-34,32, elongation at break (%) = 6,5, water absorption (%) = 20-30%. Chemical composition [1] : cellulose = 65%, lignin = 19% and ash content = 2%.

UNCONFINED COMPRESSION TEST RESULTS

THE RESULTS OF UNCONFINED COMPRESSION TEST SHOW IN FIGURE 4 BELOW.

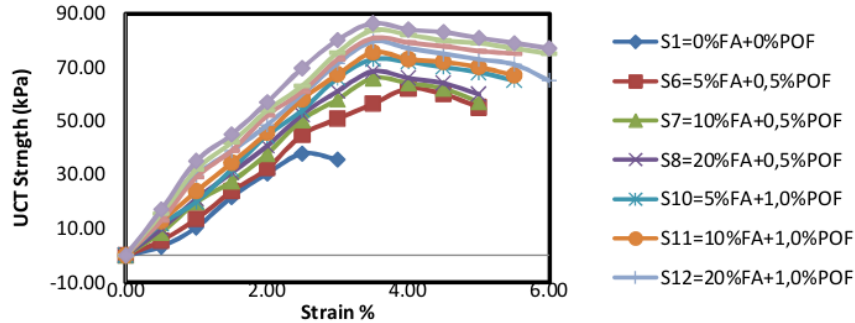


Figure 4 Relationship Of UCT Strength with variation of mix soils-fiber-fly ash

The result of mix Soil-fiber-Fly ash in unconfined compressive strength test showed that peak increase in compressive strength is at 10% of the composition of fly ash. However, peak compressive strength obtained on the addition of fiber 2% and 20% fly ash that is 86.27 kPa or increase to 128% from the initial 37.84 kPa. These results indicate that the combination of soil mix with fly ash and fibers provide the ideal solution to the increase in the compressive strength compare to just mix the soil with fiber or fly ash alone. Which in this case fly ash serves to react with water in (cementation process) to form a solid granules. While the fibers serve to reinforce the interlocking forces between the fiber and the soil surface as adhesion properties so that the soil is not easily collapse.

HYDRAULIC CONDUCTIVITY TEST RESULTS

Hydraulic conductivity test results of the mix of soils-fiber-fly ash show in Figure 5.

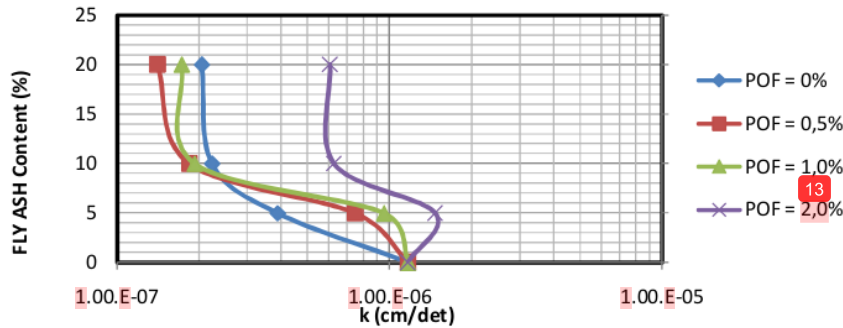


Figure 5 . Relationship Of Hydraulic Cconductivity of Mix Soils-Fiber-Fly Ash.

As the result show that generally fly ash can decrease the hydraulic conductivity of the soils. However, fiber tend to increase the value of the soils conductivity. The hydraulic cobductivity of Soil-fiber-fly ash mixture is lowest at 0.5% fiber and 20% fly ash that is about $1,2 \times 10^{-7}$ cm/sec of k, Where it was fell by 850.4% of the initial value of $1,17 \times 10^{-6}$ cm/sec. The behaviour of fiber in soils according the hydraulic conductivity value is that the natural fibers having water absorption behaviour about 20-30%. This behaviour will increase the value soils plasticity, when the soils plasticity rate hikes tend to raise the value of the hydraulic conductivity. While the decline in the value of conductivity at the addition of fly ash due to the nature of fly ash which has a smoothness and roughness of particles that can fill the voids in the soil, as the results can change the pore volume of the soils to becomes smaller.

WETTING AND DRYING CYCLES TEST MODEL RESULTS

Results of wetting and drying cycles test model show in figure 6 and 7.

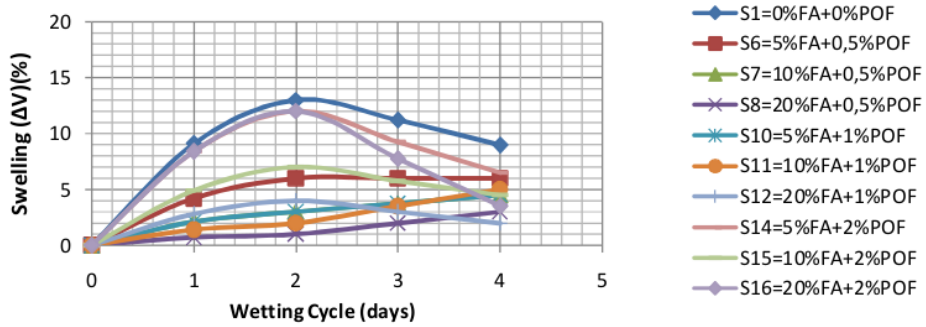


Figure 6 . Measured Of Swelling Potential in Wetting Cycles

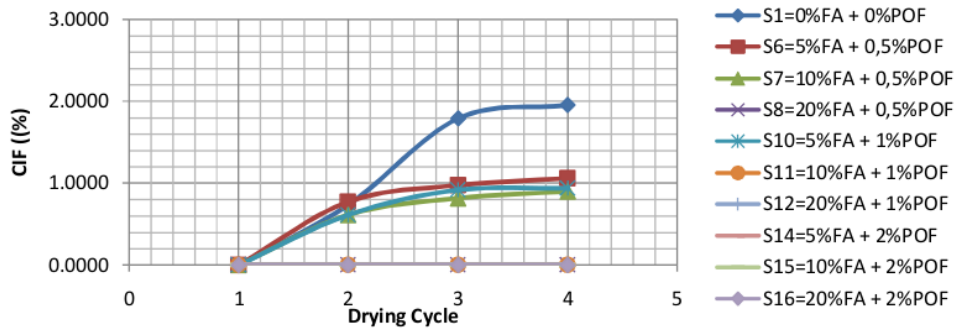


Figure 7 . Measured Of Crack Intensity Factor (CIF) in Drying Cycles

Swelling potential of the soil mixture with fiber and fly ash showed that all soil samples tend to be below the swelling potential of the natural soils. In terms of swelling potential of soils influenced by fly ash can be reduced, meanwhile fiber tend to increase the swelling potential of the soils. The higher swelling occurred at samples with 2% fiber content that is potentially swell between 3% to 6% depending on the percentage of fly ash, while the percentage of fiber 0.5% and 1% has the potential to swell between 2.5% to 5.5%. CIF results as shown Figure 6 that the mix of soils-fiber-fly ash have a significant impact on reducing the cracking potential. When only three samples from nine samples have cracks, and even then only a very small developing cracks that CIF = ± 1% at the end of the drying cycle. The higher CIF about 1,06% was occur in the percentage of fiber = 5% and fly ash = 5%. These behaviors can be concluded that a large percentage of added fiber and fly ash, the greater influence to reduce CIF. These results show that the soils-fiber has a high ability to withstand tensile force of soils-fiber interface, so that the rift was minimal. While fly ash can reduce the potential for cracking due to fly ash particle size is smaller and has the high level of roughness, thereby potentially fill voids left by the water due to soil drying. As a result, the potential for soil cracks can be reduced.

MECHANICALLY ZONE OF MIXED SOIL-FIBER-FLY ASH AS FINAL COVER LANDFILL

As for some of the mechanical parameter values required under a layer of soil as landfill final cover layer, namely: 1). hydraulic conductivity must be less than or equal to 1×10^{-5} cm / sec, for non-hazardous waste; 2). Values of crack intensity factor (CIF) should be 0%. 3). PI = 10-15%, LL = 25-30%, 4). Another restriction concerning density and unconfined compression strength should be rise at least over 50% of the initial value of soil. According to the analysis zones eligible criteria as landfill final cover layer is a mixture of soil with a percentage of 10% fly ash and 1% fiber. Where mechanically mix it qualifies as the reference layer requirements as landfill final cover.

THE TEST RESULTS OF CHEMICAL COMPOUNDS OF THE SOIL STABILIZED BY FLY ASH 10% AND FIBER 1% AS SHOWN IN TABLE I.
 TABLE I - CHEMICAL COMPOUNDS OF THE SOIL STABILIZED BY FLY ASH 10% AND FIBER 1%

TYPES OF MINERALS	MINERALS COMPOSITION	CONTENT (%)
Quartz, syn	Si O ₂	62
Mullite, syn	Al _{4.56} Si _{1.44} O _{9.72}	4
hematite HP, iron(III) oxide	Fe ₂ O ₃	0,2
Rutile, syn	Ti O ₂	4,5
Albite	Na (Al Si ₃ O ₈)	26
calcium tecto-dialumodisilicate, anorthite HP	Ca (Al ₂ Si ₂ O ₈)	3,7

As shown in table I as results of X-Ray diffraction test that the chemical compound of silica (Si O₂) decrease from 67% to be 62%, and the compound of alumina has increased to 26% from 17%. This results showed the fly ash hydration process in a mixture of soil and fly ash that produce new compound of mineral calcium silica hydrate (CSH) such as Al Si₃ O₈ = 26%, Al₂ Si₂ O₈ = 3,7% and Al_{4.56} Si_{1.44} O_{9.72} = 4%. The total amount of the new compound calcium silika is 33,7%. Of calcium silica hydrate (CSH) covers around granular soil with a slow time so that the soil becomes solid and hard. Soil fly ash reinforced fibers can improve strength, resist deflection of crack initiation, slow deformation and increases the resistance of the shear. Serves to hold the fiber tensile force, increasing the shear strength between soil and fiber due to the interaction interface palm oil fibers and fly ash absorption in the soil. Palm oil fibers containing cellulose and lignin chemical compounds that can potentially react with the soil and fly ash.

SOIL HYDRAULIC CONDUCTIVITY MODEL

Unsaturated hydraulic conductivity testing with the air pressure is performed at optimal fiber content of 1.0% and 10% fly ash by a mechanical criteria zone in the previous test. With a value of 95% soils density. The results of the measurement is done with three types of liquids, namely leachate, aquades and mixed of leachate and aquades. The liquids was conducted in viscosity test with results of viscosity (ρ) in (poise). The value of viscosity of Aquades = 1.003 x10⁻², leachate = 3,2x10⁻² and mixed aquades and leachate = 2,1x10⁻². Hydraulic conductivity model results shown in figure 7.

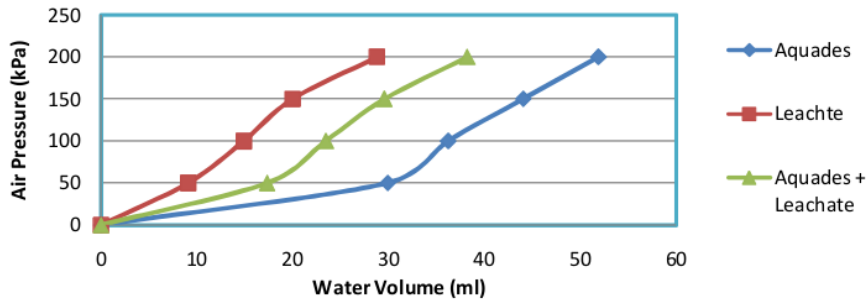


Figure 7 Relationship Of Air Pressure and Volume of Water with 3 types of liquids (leachte, aquades and mixed of leachte and aquades)

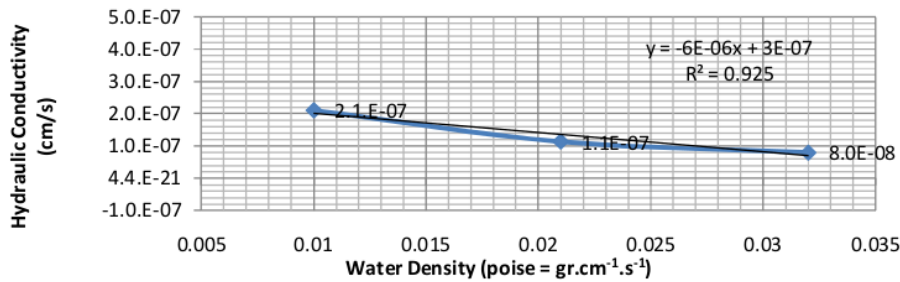


Figure 8 Measured Of Hydraulic Conductivity Model Of Soils with Water Density

Model of soil hydraulic conductivity of mix soils-fiber-fly ash show that a linear relationship between the viscosity of the soil with soil conductivity value, where the relation of it is $R^2 = 0.925$. This illustrates that the more viscous the soils will have an impact on the increase of soil hydraulic conductivity. Where the opportunity fluid with high viscosity will be more difficult to pass through the soils mass. mathematical equation relationship with viscosity hydraulic conductivity of leachate namely:

$$y = -6E^{-06x} + 3E^{-7}$$

The equation model of the relationship between viscosity and hydraulic conductivity of the soils applied for that soils namely silty sand with have a fraction of clay stabilized by 10% of fly ash and 1% of palm oil fiber.

IV. CONCLUSION

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Based on the results presented above, it can be concluded as follows:

- As results of X-Ray diffraction for soils interaction with 1% fiber and 10% fly ash show the fly ash hydration process in a mixture of soil and fly ash that produce new compound of calcium silica hydrate (CSH) about 33,7%. Where the CSH covers around granular soil with a slow time so that the soil becomes solid and hard. Soil fly ash reinforced fibers can improve strength, resist of crack intensity factor, resist of shrinkage and swelling potential, and increases the resistance of the shear,
- The mechanical behavior of soils-fiber-fly ash on the unconfined compressive strength test show the rose on value of average above 70% of the initial value. These results indicate that the combination of soil mix mix-fly ash-fibers provide the ideal solution to the increase in the compressive strength of soils. fly ash serves to force a grain of soil due to reaction with water (cementation) form a solid granules. While the fibers serve to reinforce the attraction between the fiber and the soil surface for adhesion properties so that the soil is not easily collapse. Hydraulic conductivity test results that the addition of fiber demonstrates the potential for an increase in the value of the conductivity of the soil. While a decline in the value of conductivity at the addition of fly ash. This is due to the nature of fly ash which has a smoothness and roughness of high particle so as to fill the voids in the soil and can change the volume of pores in the soil to be small.
- The addition of fiber tend to increase the potential for the swelling of nature soils. Instead the addition of fly ash tends to degrade the nature of the original soils swelling. However, the CIF where only occur in three samples from nine samples have cracks, the cracks are very small in the CIF = ± 1%. This behavior shows that soil-fiber has a great ability to withstand tensile strength fiber soil interface, so that cracking and shrinkage that occurs is very small. While fly ash can reduce the potential for cracking due to fly ash particle size is smaller and has the high level of roughness, thereby potentially fill voids left by the water due to soil drying.
- Model of hydraulic conductivity soils with air pressure shows that the effect of viscosity of water (ρ) that effect the ability of liquid to go through a soil mass, especially in compacted soil conditions. Model of soil hydraulic conductivity is showing as a linear relationship between the viscosity of the soil with soil conductivity value, where the value of $R^2 = 0.925$. This illustrates that the more viscous of the soils will have an impact on the increase of the soil hydraulic conductivity.



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