Study of the Effect of Organic Geopolymer for Soil Stabilization Materials as Main Road Subgrade

by Ahmad Saiful Haqqi

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Study of the Effect of Organic Geopolymer for Soil Stabilization Materials as Main Road Subgrade

Pakar Gunawan Manalu[1], Rusdiansyah[2]
[1]The Student of Civil Engineering Master Program at Lambung Mangkurat University
[2]The Teaching Staff of the Civil Engineering Master Program at Lambung Mangkurat University
Email: pmanalu.work@gmail.com

Abstract— *Soil stabilization is an effort to improve soil properties, increase soil carrying capacity and soil shear strength by mixing it with chemicals or other additives. Stabilizing the soil aims to increase soil density, replace inactive materials to increase cohesion and friction resistance that arises, adding it to change soil's chemical and/or index, reduce the soil drainage, replace bad soil so that it has technical specifications as subgrade for highway pavement. The most commonly used and best-considered soil chemical stabilization material for soil is cement but it has a negative impact so organic geopolymer used instead of it. The organic geopolymer forming material derived from oil palm shell ash and alkali activator are NaOH.*

Based on the results of soil index properties, the initial PI soil test results was 22.92% and after the addition of organic geopolymer become 15.70%. Soil engineering properties test in the form of standard compaction testing, CBR laboratory and unconfined compression test (UTC). The initial standard compaction test for the soil maximum dry density soil was 14,00 kN/m^3*, and the optimum water content was 29.39%, after adding organic geopolymer the weight become 14,80 kN/m*^{3}*, and optimum water content become 25.35 % (qualify). The initial CBR soil test results were 6.9%, but after the addition of CBR organic geopolymer become 8.7% (qualify). The initial soil UCT results were 59,87 kPa, after the addition of UCT organic geopolymer become 90,91 kPa (qualify).*

Keyword— *Stabilization, Subgrade, NaOH, CBR, UCT, Proctor Standar.*

I. Preliminary

Soil index properties and soil engineering properties like soft soil, is insufficient to be used as the material for road transport infrastructure. Therefore, we need to stabilization it for technical requirements. Soil stabilization is an effort to improve the properties, increase it's carrying capacity and shear strength by mixing it with chemicals or other additives, that used for stabilization so far are lime, fly ash, cement and many other examples in general to achieve stability in the soil.

The most commonly used and considered the best stabilization material for soil is cement. It can increase the carrying capacity effectively (Muda, 2011). By Muda's study (2011) showed that a mixture of 12% sand and 2% of cement produced a CBR value of 5.80%. Then, stabilizing with 4% cement, the CBR value rises become 38% and 6% cement obtained CBR value 48%. Then, 8% cement mixture obtained a CBR value of 56% and 10% cement obtained by CBR value 62%. As evidenced by the addition of cement, the CBR value is increasing.

Andi's research (2015) on the Study of Granite Soil of Hampalit Village in Central Kalimantan which Stabilized with Cement and Additives showed UCT values with a mixture of granite soil with cement content of 4,5%, 5%, 5,5%, 6% and 6,5% were 12,9 kg/cm2, 18,56kg/cm2, 25,06kg/cm2, 28,47kg/cm2 and 33,51 kg/cm2 respectively. UCT values with cement soil mixtures increase when cement levels increase. But cement has a negative impact, for example, to produce one ton of cement, the energy needed can reach 110-120 kWh, and the raw material needed for total weight is almost double the final product it produces. Geopolymer is cement replacement materials that demand to reduce the negative impact of cement.

So far, there have been many studies using rock ash or oil palm shell ash which contains high silica as a soil stabilization material but has never been mixed with alkaline solutions as commonly used in geopolymer concrete.

Geopolymer has only been used for concrete but it is possible to use it as a soil stabilization material. In this study, the geopolymer material used was oil palm shell ash, and alkali activator is NaOH. According to Hutahaean (2007), oil palm shell ash has a SiO2 content of 58.02%, Al2O3 8.7%, and CaO 12.65%. Geopolymer can be expected to affect soil stabilization to improve index properties and increase soil strength. This research uses Betung Street's soil, Katingan Regency, Central Kalimantan Province.

According to Davidovits (2015), geopolymer is material that contain a lot of *silica* and high *alumina* that activated using activators of alkali solutions such as NaOH, etc.

Based on the description above, the problem can be formulated: (1) How is the index of the soft soil before and after stabilization? (2) What is the effect of the percentage of geopolymer addition on density (*Proctor Standard*), unconfined compression test (*UCT*) and *CBR*? (3) What are the characteristics of soil chemistry and organic geopolymer using the EDX method? (4) What is the effect of adding organic geopolymer to microscopic soil using the SEM method?

The problems limitation of soil stabilization research with organic geopolymer is: (1) The material used is undisturbed soil from Dusun Betung Street, Katingan Regency, Central Kalimantan Province (2) The geopolymer stabilization material used is oil palm shell ash from PT.Karya Dewi Putra (KDP), Katingan, Central Kalimantan from oil palm plant combustion (3) The alkali activator is NaOH (Sodium Hydroxide) (4) The study only tested the soil index properties and engineering properties mixtures not their chemical (5) Characteristic data obtained from the results of research in the laboratory that will be match with existing theories without discussing in depth the chemical elements.

The objectives of the soil stabilization research with organic geopolymer are: (1) Identifying the soil's index properties. (2) Analyzing the effect of adding geopolymer on the soil density (*Proctor Standard*), unconfined compression test (*UCT*) and *CBR*. (3) Identifying the soil chemical content and organic geopolymer using the EDX method. (4) Analyzing the behavior of soil mixtures and organic geopolymer using the results of SEM (*Scanning Electron Microscope*)

The benefits of this research are: (1) To provide new knowledge about soil stabilization materials, especially geopolymer. (2) Obtain an overview of the effect of adding geopolymer on soil mixtures to density (*Proctor Standard*), swelling, unconfined compression test (*UCT*) and *CBR*. (3) Utilizing useless waste into appropriate use materials so that it has economic value for the region. (4) Providing information to the local government of Katingan Regency to utilize oil palm shell ash.

II. Literature Review

Soil Stabilization

Soil stabilization is the process of mixing it and binding materials to improve the it's technical properties. Soil stabilization carried out if the land is very loose or very easily depressed, or if it has an inconsistent consistency index, too high permeability, or other undesirable properties that are not suitable for a development project, then the land must be stabilized.

Organic Geopolymer

Geopolymer is cement replacement binders that less environmentally friendly. Organic geopolymer is made using oil palm shell ash which contains high *silica* and *alumina* and mixed with alkali solution as an activator to produce a binding material. The alkali solution used in this study was NaOH (sodium hydroxide). The explanation of the organic geopolymer materials used are as follows :

1. *Oil palm shell ash* is *pozzolanic* material, which is the material that forms cement, which contains *silica* compounds (SiO2) can react with free lime or calcium hydroxide (CaOH2) and water that will form cement material named calcium silicate hydrate (C-S-H). The test results of the chemical composition of oil palm shell ash that have been carried out by Hutahaean (2007) are in the Table 1:

Table 1. Chemical Elements of Palm Oil Shell (Hutahaean, 2007)

Chemical Elements	Percentage (%)
SiO_2	58,02
Al_2O_3	8,7
Fe_2O_3	2,6
CaO	12,65
MgO	4,23
Na_2O	0,41
K_2O	0,72
H2O	1,97
Lost incandescent	8,59

2. *Alkali solution* is used as an activator to produce *polymeric bonds*. Alkali used is NaOH or *Sodium Hydroxide*. The function is to react to Al and Si contained in the ash of oil palm shells and soil to produce strong *polymeric bonds*.

III. Research Methods

Sampling Method

The soil samples are disturbed soil samples and undisturbed soil samples, located on Dusun Betung Street, Katingan Regency, Central Kalimantan Province. The soil was took as material for testing the index properties and index engineering of disturbed soil.

Mixed Order

In this research, the sequence is as follows:

This research is experimental to determine the composition and activity of organic geopolymer mixture, in the form of oil palm shell ash with alkali NaOH solution. The stages of research carried out include:

1. Preparation of material test
2. Examination of the Soil index properties and soil engineering properties.
3. Make Organic Soil Mixes and Geopolymer.
4. Organic Soil Mixes and Geopolymer Test.
   The first test was soil with oil palm shell ash with levels 5%, 7.5%, 10%, 12.5%, and 15%. The maximum results of the test then being tested again with the addition of alkali NaOH with levels 0%, 2%, 4%, 6%, and 8%.
5. Analysis
6. Conclusion

Tests and Analysis

Soil index properties test :

1. Water content test.
   Based on SNI 1965: 2008.
2. Specific gravity test.
   Based on SNI 1964: 2008.
3. Grain test/sieve analysis.
   Based on SNI 03-1968-1990.
4. Liquid limit test.
   Based on SNI 1967:2008.
5. Plastic limit test.
   Based on SNI 1966:2008.
6. Plastic index test.
   Based on SNI 1966:2008
7. Hydrometer analysis test.
   Based on SNI 3423:2008.

Soil index engineering test :

1. Compaction test.
   Based on SNI 1742:2008.
2. CBR test (*California Bearing Ratio*).
   Based on SNI 1744:2012.
3. Unconfined compression test (*UCT*)
   Based on SNI 6887:2012.

International Research Journal of Advanced Engineering and Science
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Index Properties Test

Soil index properties are original soil nature in an undisturbed state to determine water content, and disturbed conditions include Specific Gravity (GS), sieve analysis, hydrometer analysis and Atterberg boundaries (liquid limit, plastic limit, and plastic index) used to determine the type of soil. The results of the recapitulation of soil index testing are as shown in Table 2 as follows:

Table 2. Recapitulation Soil Index Properties

Test	Test Standard	Sample 1	Sample 2	Sample 3	Mean
Water content (%)	SNI 1965:2008	45,68	48,91	47,69	47,43
Specific Gravity	SNI 1964:2008	2,60	2,61	2,61	2,61
Atterberg boundaries					
Liquid limit (%)	SNI 1967:2008	47,00	47,50	45,60	46,70
Plastic limit (%)	SNI 1966:2008	23,64	25,34	22,37	23,78
Plasticity index (%)	SNI 1966:2008	23,36	22,16	23,23	22,92
Sieve analysis and hydrometer analysis (%)	SNI 03-1968-1990 SNI 3423:2008	0,43	0,70	0,38	0,50
Course Sand(%)		0,38	0,34	0,43	0,38
Medium Sand (%)		0,38	0,39	0,53	0,43
Fine Sand (%)		3,11	3,61	4,56	3,76
Silt and Clay(%)		33,36	38,51	32,09	34,66
Clay (%)		62,33	56,45	62,01	60,27
Classification	USCS/ AASHTO	Sandy clay			

Source: Laboratory Examination Results (2018)

Engineering Properties Test

Soil engineering properties are the soil nature used in the foundation. The Index engineering test in the laboratory includes Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), California Bearing Ratio (CBR laboratory), swelling with immersion for four days and Unconfined Compression Test (UTC). The recapitulation result of soil engineering properties are as shown in Table 3 as follows:

Table 3. Recapitulation Soil Engineering Properties

Test	Test Standard	Sample 1	Sample 2	Sample 3	Mean
Maximum Dry Density (kN/m^3)	SNI 1742:2008				14,00
Optimum Moisture Content (%)					29,39
CBR Laboratory					
CBR 100% (%)	SNI 1944:2012				6,9
Unconfined Compression Test (kPa) *UCT Undisturbed*	SNI 6887:2012	60,40	58,15	61,06	59,87

Source: Laboratory Examination Results (2018)

Soil Index Properties Test with Organic Geopolymer

Soil index properties with organic geopolymer are to determine the effect of the soil index properties when added by organic geopolymer with mixed variations that determined. The addition of organic geopolymer in this test was carried out in stages with the addition of oil palm shell ash after added NaOH from the optimum yield of soil content + oil palm shell ash. The recapitulation result of soil index properties with organic geopolymer is in Tables 4 and 5 as follows:

Table 4. Recapitulation Soil Index Properties Mixture with Oil Palm Shell Ash

Test	Test Standard	Soil	Soil Mixture with Oil Palm Shell Ash (ACKS)				
			5%	7,5%	10%	12,5%	15%
Water Content (%)	SNI 1965:2008	47,43	-	-	-	-	-
Specific gravity	SNI 1964:2008	2,61	-	-	-	-	-
Atterberg boundaries							
Liquid Limit (%)	SNI 1967:2008	46,70	44,20	43,80	42,50	43,10	44,70
Plastic Limit (%)	SNI 1966:2008	23,78	22,79	23,32	23,70	22,97	22,28
Plastic Index (%)	SNI 1966:2008	22,92	21,41	20,48	18,80	20,13	22,42
Sieve analysis and Hydrometer	SNI 03-1968-						
Gravel (%)	1990	0,50	-	-	-	-	-
Course Sand (%)	SNI	0,38	-	-	-	-	-
Medium Sand (%)	3423:2008	0,43	-	-	-	-	-
Fine Sand (%)		3,76	-	-	-	-	-
Silt and Clay (%)		34,66	-	-	-	-	-
Clay (%)		60,27	-	-	-	-	-
Classification	USCS/AASHTO	Sandy clay					

Source: Laboratory Examination Results (2018)

Table 5. Recapitulation Soil Index Properties with Organic Geopolymer

Test	Test Standard	Soil + ACKS	Soil mixture with Organic Geopolymer			
			2%	4%	6%	8%
Water Content(%)	SNI 1965:2008	47,43	-	-	-	-
Specific gravity	SNI 1964:2008	2,61	-	-	-	-
Atterberg boundaries						
Liquid Limit (%)	SNI 1967:2008	42,50	41,30	40,50	39,50	36,30
Plastic Limit (%)	SNI 1966:2008	23,70	24,17	23,68	23,10	2060
Plastic Limit (%)	SNI 1966:2008	18,80	17,13	16,82	16,40	15,70
Sieve analysis and Hydrometer	SNI 03-1968-1990 SNI 3423:2008					
Gravel (%)		0,50	-	-	-	-
Course Sand (%)		0,38	-	-	-	-
Medium Sand (%)		0,43	-	-	-	-
Fine Sand (%)		3,76	-	-	-	-
Silt and Clay (%)		34,66	-	-	-	-
Clay (%)		60,27	-	-	-	-
Classification	USCS/AASHTO	Sandy Clay				

Source: Laboratory Examination Results (2018)

Soil Engineering Properties Test with Organic Geopolymer

Soil engineering properties are the soil nature used as a parameter in carrying capacity planning. The soil engineering properties test in this study includes CBR (California bearing ratio), compacting test, swelling, unconfined compression test (UTC). Soil engineer properties test by adding organic geopolymer was to determine the effect of soil engineering properties when added by organic geopolymer with mixed variations that determined. The addition of organic geopolymer in this test was carried out in stages as the soil index properties test with organic geopolymer before. The recapitulation result of soil engineering properties with organic geopolymer mixtures as in Tables 6 and 7 below:

Table 6. Recapitulation Soil Engineering Properties Test Mixture With Oil Palm Shell Ash

Test	Test Standard	Soil	Soil Mixture with Oil Palm Shell Ash (ACKS)				
			5%	7,5%	10%	12,5%	15%
Maximum Dry Density (kN/m^3)	SNI 1742:2008	14,00	14,30	14,60	14,80	14,50	14,10
Optimum Moisture Content (%)		29,39	28,20	27,62	25,35	26,21	28,51
CBR Laboratory CBR 100% (%)	SNI 1944:2012	6,9	7,3	7,9	8,1	7,7	7,1
Unconfined Compression Test/UCT (kPa) *UCT Undisturbed*	SNI 6887:2012	59,80	64,70	71,92	76,40	67,38	59,70

Source: Laboratory Examination Results (2018)

Table 7. Recapitulation Soil Engineering Properties with Organic Geopolymer

Test	Test Standard	Soil + ACKS	Soil mixture with Organic Geopolymer			
			2%	4%	6%	8%
Maximum Dry Density (kN/m^3)	SNI 1742:2008	14,80	15,00	15,10	15,30	15,50
Optimum Moisture Content (%)		25,35	24,89	23,39	22,60	21,47
CBR Laboratory CBR 100% (%)	SNI 1944:2012	8,1	8,2	8,4	8,5	8,7
Unconfined Compression Test/UCT (kPa) *UCT Undisturbed*	SNI 6887:2012	76,41	82,99	85,15	87,84	90,91

Source: Laboratory Examination Results (2018)

SEM-EDX Test

SEM-EDX test is additional testing to determine the morphology or topography of the sample and to know the composition elements quantitatively. The SEM test results used for analysis are 1000x magnification (1000 times) to obtain the appropriate it and uniformity.

From previous tests (index and engineer tests) that the addition of 10% oil palm shell ash could increase the CBR values and decrease the plasticity index (PI) of soils, but in addition of more than 10% (> 10%) oil palm shell ash make decrease of values CBR and increase the plasticity index (PI). Then the addition of 2% - 8% NaOH from the addition of the optimum oil palm shell ash also increased with the addition. The samples that tested in here were :

1. Soil
2. Oil Palm Shell Ash (ACKS)
3. Soil + ACKS 10%
4. Soil + ACKS 15%
5. Soil + ACKS 10% + *NaOH* 2%
6. Soil + ACKS 10% + *NaOH* 8%

Next is the EDX test results used to analyze it based on the weight percent of the sample tested and included in the tables and spectrum images. The EDX test results are as follows:

Table 8. EDX Test Result of Element Composition

Element Composition	Sample Weight (%)					
	Soil	Oil Palm Shell Ash (ACKS)	Soil + ACKS 10%	Soil + ACKS 15%	Soil + ACKS 10% + NaOH 2%	Soil + ACKS 10% + NaOH 8%
C K	18,7	20,53	33,6	36,8	-	-
O K	6	38,54	42,33	40,58	46,79	49,69
Al K	45,6	0,82	5,43	3,41	7,65	10,3
Si K	5	14,8	13,28	13,82	28,32	23,03
Fe K	9,11	-	3,07	2,9	5,43	5,19
Mg K	19,8	0,85	0,13	0,22	0,19	0,32
P K	3	1,12	-	-	-	-
S K	6,65	2,18	-	-	-	-
Cl K	-	2,99	-	-	-	-
K K	-	13,01	0,89	1,31	1,55	1,23
Ca K	-	5,16	1,26	1,31	1,54	1,29
Na K	-	-	-	-	8,53	8,95
	-					
	-					
	-					
Total	100	100	100	100	100	100

Source: Laboratory Examination Results (2018)

From the table, soil contains Si (*Silicon*), Al (*Alumina*) and Fe (*Ferrum*) elements that reacted with O (*Oxygen*) become SiO_2 (*Silicon Oxide*), Al_2O_3 (*Aluminum Oxide*) and Fe_2O_3 (*Ferric Oxide*).

Based on the elemental composition above, oil palm shell ash can be function as a *pozzolanic* which is a cement-forming material, which can react with CaOH2 (Calcium Hydroxide) or NaOH (Sodium Hydroxide) and water that will form cement minerals named C-S-H (Calcium Silicate Hydrate).

The following are the results of the SEM test of 1000x (1.00k) magnification which is used to be uniform to analyze morphological changes after the addition of ingredients added to oil palm shell ash and NaOH (Sodium Hydroxide). The images from the SEM test are as follows:

Soil SEM

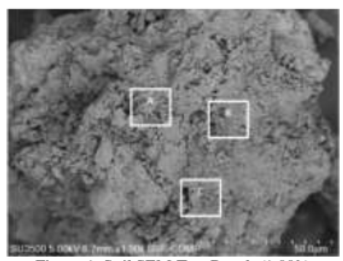

Figure 1. Soil SEM Test Result (1.00k)

Based on preliminary observations of soil from Figure 1, in positions A, B and C there are soil pores and sheet-shaped soil texture.

From Figure 1, it can be seen that the initial condition of the inter-particle soil is far enough before the addition of oil palm shell ash and NaOH. In Figure 3, there is a reaction of the addition of 10% oil palm shell ash which covers the pore and attaches particles to increase soil density. In Figure 4, the distance between particles is increasingly dean, but the pore number becomes large again with the addition of 15% oil palm shell ash. In Figure 5 and 6 the soil become more constructive after addition of NaOH, the pores shrink and granules shaped like sheets. From this analysis, it was concluded that after addition of oil palm shell ash and NaOH can be used as soil stabilization material instead of cement.

Oil Palm Shell Ash (ACKS) SEM

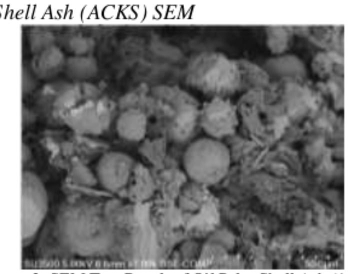

Figure 2. SEM Test Result of Oil Palm Shell Ash (1.00k)

Soil SEM + ACKS 10%

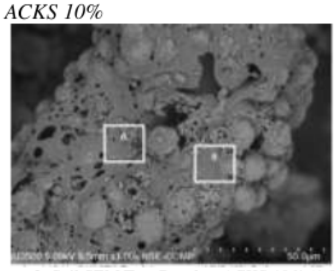

Figure 3. Soil SEM Test Result + ACKS 10% (1.00k)

Soil SEM + ACKS 15%

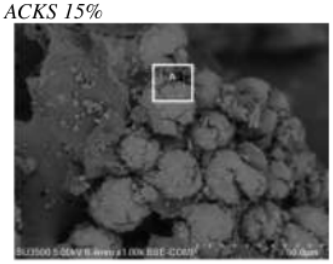

Figure 4 Soil SEM Test Result + ACKS 15% (1.00k)

Soil SEM + ACKS 10% + NaOH 2%

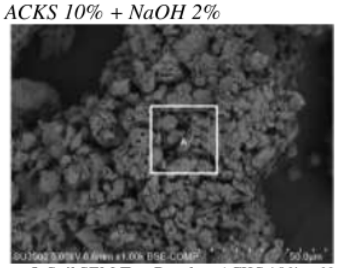

Figure 5. Soil SEM Test Result + ACKS 10% + *NaOH* 2% (1.00k)

Soil SEM + ACKS 10% + NaOH 8%

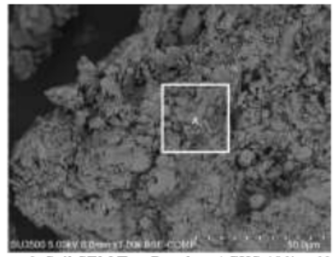

Figure 6. Soil SEM Test Result + ACKS 10% + *NaOH* 8% (1.00k)

IV. Conclusion

The soil index properties before and after stabilization with organic geopolymer become decrease in the liquid limit and an increase the plastic limit so that the plasticity index also decreases.

The effects of the optimum percentage of organic geopolymer addition on the soil in the density test (Proctor Standard) are maximum dry density increases and the moisture content decreases (technical specification qualify).

The effect of the percentage of organic geopolymer addition on the soil in the UCT test is that the value increases with addition (technical specification qualify) and also the CBR test value increases with the addition of organic geopolymer (technical specification qualify).

Soil content used as the sample are C (*Carbon*) = 18,76%, O (*Oxygen*) = 45,65%, Al (*Aluminium*) = 9,11%, Si (*Silicon*) = 19,83% and Fe (*Ferrum*) = 6,65%. After the added of the optimum percentage of organic geopolymer, the content become O (*Oxygen*) = 49,69%, Na (*Sodium*) = 8,95%, Mg (*Magnesium*) = 0,32%, Al (*Aluminium*) = 10,3%, Si (*Silicon*) = 23,03%, K (*Potassium*) = 1,23%, Ca (*Calcium*) = 1,29% dan Fe(*Ferrum*) = 5,19%.

The effect of adding organic geopolymer to soil from a microscopic point of view that makes soil density increase, reduce the pore and, granular texture more constructive.

V. Suggestion

Based on the results of data analysis and the discussions that:

Stabilization methods with organic geopolymer by replacing other materials containing *silica* and high *alumina*, also by replacing types of alkali as organic geopolymer activator.

This method of stabilizing soil with organic geopolymer used as a substitute for cement that is more environmentally friendly and inexpensive because it uses oil palm shell ash that is not used and has no selling value from oil palm factory.

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