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Microstructural and Mechanical Characteristic of Potential Ferro Laterite Soil as Sub-base Material

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Abstract— This study aimed to determine and evaluate the characteristics and behavior of the mechanical and microstructural of ferro laterite soil to be used as sub-base material. Ferro laterite soil obtained from three different sampling sites at the East Halmahera Regency. The sampling process of conventional excavation on the surface, soil sample is inserted into the sample bag and labeling as LH1 for first location, LH2 for the second location, and LH3 for a third location. Furthermore, soil prepared for testing the physical properties. The standard proctor compaction test is performed to determine the optimum water content and maximum density of soil, then used as the basis for sample preparation. Soil strength testing used unconfined compression test and soil bearing capacity used CBR laboratory test, before being tested, each sample cured for 3, 7, 14, and 28 days. While the microstructural behavior used XRD and SEM-EDS testing. The results show that density and soil strength tend to increase with the curing time, and directly increase of CBR values. Based from both test results, mechanical and microstructural characteristic, potential ferro laterite soil of East Halmahera Regency can be developed and utilized as sub base material, but need a detailed study on the possibility of increasing its ability with soil stabilization to give more confidence before used.

Keywords— Characteristics of ferro laterite soil, unconfined compression stength, bearing capacity, microstructure, sub-base material

I. INTRODUCTION

Geographically and geologically, Indonesia is an area rich in minerals, especially metal formed from ultramafic rocks, causing the spread of laterite in almost every area. Distribution of ferro laterite soil on the island of Halmahera in North Maluku Province is very dominant in the east. Halmahera ferro laterite soil is soil that forms in the tropics or sub-tropics with a very high level of weathering on mafic and ultramafic rocks, which implies dominated by ferrous metals (Spatial Plans of East Halmahera Regency, 2010-2015).

Laterite soil contains clay minerals are relatively high mainly illite and montmorillonite (Portelinha, et.al., 2012), so the potential for damage is greater if the construction work carried out on the soils like this. Clay minerals and metals are high, it can be used for all types of construction, industry, and others. Need to study the characteristics of the soil and the possibility of repair before use, one potential use is as a sub-base material.

Laterite soil is the result of very high weathering, soil group, formed from the concentration of hydrated iron oxide and aluminum (Thagesen 1996 from Olugbenga et.al, 2011). Laterite name given by Buchanan, 1807 in India, from the Latin word "later" which means bricks. The soil type has the characteristics of a hard, impenetrable, and very difficult to change if dry conditions (Makasa, 2004; Olugbenga et.al, 2011). Laterite has a wide range of red, yellow to brown, fine grain with a grain size of the soil residual light texture has a nodular shape and cemented well (Lambe and Whitman, 1979). Bridges (1970) state that the correct use of the term laterite is a compact rock formations vesicular iron (a large vesicular or ironstone formation concretionary). Fookes (1997) called laterite based hardening as "freeic" for hard soil rich in iron are cemented, "alcrete" or bauxite for hard soil that is rich in aluminum are cemented, "calcrete" for hard soil rich in calcium carbonate, and "silcrete "for silica-rich. Another definition is based on a comparison of the amount of silica (SiO2) to oxide (Fe2O3 + Al2O3), for comparison such as laterite between 1.33 and 2.0, while above 2.0 is not laterite.

The composition of elements and compounds contained in laterite soil that is common in Indonesia, including oxygen, magnesium, aluminum, silicon, sulfur, calcium, vanadium, manganese, iron, and nickel. While the mineral content contained in laterite soil consists of hematite, kaolinte, illite, montmorillonite, rutile, forsterite, Andalusite, magnetite, magnesium silicate, and nickel dioxide.

Physical characteristics in nature in general, is often called the soil of red-brown color is formed in humid, cold, and perhaps a puddle. This soil has a depth profile, easy to absorb water, has a moderate content of organic matter and pH neutral to acidic with a lot of metal content, particularly iron and aluminum, as well as good use as a base material to absorb water and the texture is relatively solid and sturdy.

Physical properties of laterite soil vary greatly depending on the mineral composition and particle size distribution, granulometri can vary from subtle to gravel depending on the origin and formation process that will affect Geotechnical properties such as plasticity and compressive strength. One of the advantages of laterite not swell with water, depending on the amount of clay mineral content.

The soil with a very high content of clay mineral montmorillonite is a separate issue if these soils was used for Geotechnical works, both as a construction material and subgrade. To cope with the condition of the soil as this can be done by the method of soil improvement in several ways such as; mechanical repairs (compaction), enhanced by drying (dewatering), improvement (soil stabilization) by chemical means or by the method of soil reinforcement.

Based on the above conditions, it can be said that the Halmahera ferro laterite soil is the potential for a tremendous asset to spread so dominant, especially on eastern part. On the other hand, the construction of the road along with the growth of construction will require building materials, especially the sub-base material is high, while the sub-base materials (aggregate A and B) is very limited.

East Halmahera potential ferro laterite soil as a local asset (local content) can be used as the sub-base material. It is necessary for a detailed study of ferro laterite soil characteristics obtained from three different locations in the eastern part of the Halmahera Island. The characteristics include physical, mineralogy, chemical, mechanical, and microstructure.

II. MATERIAL AND METHOD

The material used in this study is ferro lateritic soil from eastern Halmahera Island, with three different sampling locations. Subaim location with coordinates 1º3'46,24"N and 128º8'28,56" E, Buli location on coordinate 0º55'13,29 "N and 128º21'5,15" E, and Maba location with coordinate 0º40 ' 17.80” N and 128º16'51,20 "E (Fig. 1).

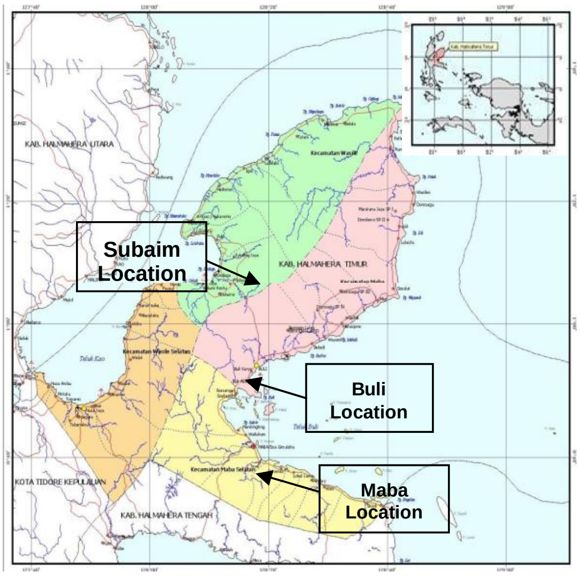

Fig. 1 Ferro laterite sampling on 3 different location of East Halmahera Regency

Soil sampling with conventionally processing using crowbars and shovels, then the soil sample was placed in a sample bag and wrapped in plastic to maintain the original moisture content, and then labeled initials correspond to sampling location of LH1 to samples from first location, LH2 for sample from second location, and LH3 to samples from third location (Fig. 2).

Fig. 2 Typical ferro laterite soil sampling results, LH1 (Subaim location), LH2 (Buli location), LH3 (Maba location)

This study is an experimental research conducted in the laboratory to determine the characteristics of lateritic soil as sub-base material. Laboratory tests to determine the physical properties include moisture content, soil consistency and specific gravity. While testing the mechanical properties include compaction test, compressive strength test, and bearing capacity test. Soil consistency using the Atterberg limit tests, compaction tests then conducted using standard Proctor compaction test, the result of compaction test that used as a basis for sample preparation, sample was cured for 3, 7, 14, and 28 days before testing. Soil strength used unconfined compression test, while the soil bearing capacity tested using CBR test, and microstructure tested using XRD test, and SEM-EDS test.

The tools used previously inspected and calibrated conditions and capabilities. Procedures of working tools to be studied carefully for accuracy, and capacity of the device should be well understood in order to avoid mistakes during testing. soil samples were prepared in accordance with standard procedures in each test. The tools will be used, previously inspected the conditions. capability and calibrated beforehand. The procedures and works mechanism to be studied carefully, ability, accuracy, and capacity of the device should be well understood in order to avoid mistakes during testing. Soil samples were prepared in accordance with standard procedures in each test.

Ferro laterite soil was added with water and weighed in the composition according to the results of compaction and cured for 24 hours until it reaches an equilibrium condition before the test. Sample were made in a cylindrical shape with size H = 2D, made by mixing ferro laterite soil with water in optimum moisture content condition, and inserted into a mold that has been lubricating oil, then compaction with 25 times blows for each section. Sample was cured for 7, 14, 21, and 28 days before being tested. microstructural behavior is tested by testing XRD, SEM, and EDS. XRD test to determine the mineral content contained in the soil, SEM test to obtain microstructural conditions in the soil, while the EDS test to obtain the composition of elements and compounds that are formed in the soil. Soil standard testing used refer to Table 1.

TABLE 1 - THE TESTING STANDARD USED

Type of Testing	Standard Number	
	ASTM	SNI (Indonesian Standard)
Grain size analysis	C-136-06	SNI 03-1968-1990
Liquid limit (LL)	D-423-66	SNI 03-1967-1990
Plastic limit (PL)	D-424-74	SNI 03-1966-1990
Plasticity index (IP)	D-4318-10	SNI 03-1966-2008
Spesific gravity (Gs)	D-162	SNI 03-1964-1990
Water content (Wc)	D-2216-98	SNI 03-1965-1990
Unconfined compression test (qu)	D-633-1994	SNI 03-6887-2002
Compaction test	D-698	SNI 03-1742-1989
CBR laboratory test	D-1833	SNI 03-6796-2002
XRD test	D3906-03 (2013)	
SEM test	E986-04 (2010)	
EDS/EDAX	E1508-12a	

III. RESULT AND DISCUSSION

Index properties testing program were concerned with; specific gravity, water content, density, Atterberg limit, and grain size analysis. The Laboratory testing performed prior is the basic testing for original soil such as soil properties of ferrous laterite soil by use of standard test (Table 1). Testing was conducted for a few sample points and taken randomly (3 different locations). The results of laboratory tests can be seen in Table 2 below.

TABLE 2 - INDEX PROPERTIES OF FERRO LATERITE SOIL

Physical and Mechanical Properties	Ferro Laterite Soil		
	LH1	LH2	LH3
Water content (%)	20,26	22,25	18,86
Specific gravity	2.73	2.62	2.66
% passing #200	92.32	94.89	91.75
Liquid Limit (%)	65.98	68.73	67.77
Plastic Limit (%)	47,92	41,96	48,86

Plastic Index (%)	18,06	26,77	18,91
AASTHO soil classification	A-7-6	A-7-6	A-7-6
USCS soil classification	CH	CH	CH
Optimum moisture content (%)	19,45	20,7	20.50
Maximum dry density (ton/m3)	1.769	1.773	1.780
CBR (%) – unsoaked	11,24	21,02	12,33
UCS (kPa)	71,44	128,88	75,61

Based on Table 2, it can be seen that, gradation/grain size test results showed that clay dominated the type of samples is about 91,75 to 94,89% and water content about 18,86 to 22,25%, while the specific gravity is 2,62 to 2,66 and the plasticity index is about 18,06 to 26,77. From these results, based on AASHTO and USCS soil classification that ferro laterite soil is clay with high plasticity.

Laterite soil dominated by clay minerals that have a high plasticity such as mineral montmorillonite (smectite) and illite, can swell when in contact with water in liquid or vapor. This is related to the composition of the base layer mineralogy or montmorillonite mineral unit structure. The structure of the mineral montmorillonite is an element that is formed of alumina octahedral sheet between two sheets of silica tetrahedra. An alumina octahedral structure composed of one atom of aluminum and 6 hydroxyl in which silica tetrahedral octahedral shape consisting of a silicon atom and four oxygen atoms in a tetrahedral shape (Mitchell, 1993).

Most of the clay minerals have a sheet or layered structures, several them have elongate tubular or fibrous structures. Clay particles behave like colloids, it is a particle whose specific surface is so high that its behaviour is controlled by surface energy rater than mass energy. From the viewpoints of interparticle forces, these colloidal characteristics of clay particles are similarly charged (Hamzah et.al., 2012). In considering the above mentioned characteristics; mineral, physical, and chemical contents of soil, sediment were investigated and to be conducted by the appropriate collaboration tests with other laboratory. Mineral characteristics were obtained from the result test by XRD test can be seen in Table 3 below.

TABLE 3 - MINERAL CHARACTERISTICS OF FERRO LATERITE SOIL

Mineral Content (%)	**Ferro Laterite Soil**		
	LH1	LH2	LH3
Hematite HP, iron(III) oxide	13	7	1
Kaolinite	20	8	67
Illite-montmorillonite (NR)	60	80	18
rutile HP	1	2	11
Magnesium Silicate	6	3	3

Table 3 shows that ferro laterite soil is dominated by montmorillonite and illite to LH1 (60%) and LH2 (80%), while LH3 dominated by kaolinite (67%). This shows that the LH1 and LH2 potentially to swelling soils. The chemical characteristic can also affect the ferro lateritic soil behavior if treated either mechanically or by stabilization. Chemically ferro laterite soil is dominated by iron (FeO) about 80,5 to 84,88% as shown in Table 4.

TABLE 4 - CHEMICAL CHARACTERISTIC OF FERRO LATERITE SOIL

Element (%)	**Ferro Laterite Soil**		
	LH1	**LH2**	**LH3**
MgO	2,33	0,83	1,28
Al_2O_3	4,41	5,73	8,45
SiO_2	12,58	2,28	3,71
K_2O	0,1		
TiO_2	0,08		
FeO	80,5	86,55	84,88
SO_3		1,05	
CaO		0,25	
MnO		0,24	
NiO		2,78	1,38

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Microstructural test results SEM-EDAX of ferro laterite soil further clarify the conditions of mineral and chemical characteristics, it appears that the dominance of illite and montmorillonite in sheet form mutually bonded to each other and form clumps with large micro-pores condition, as shown in Figure 3.

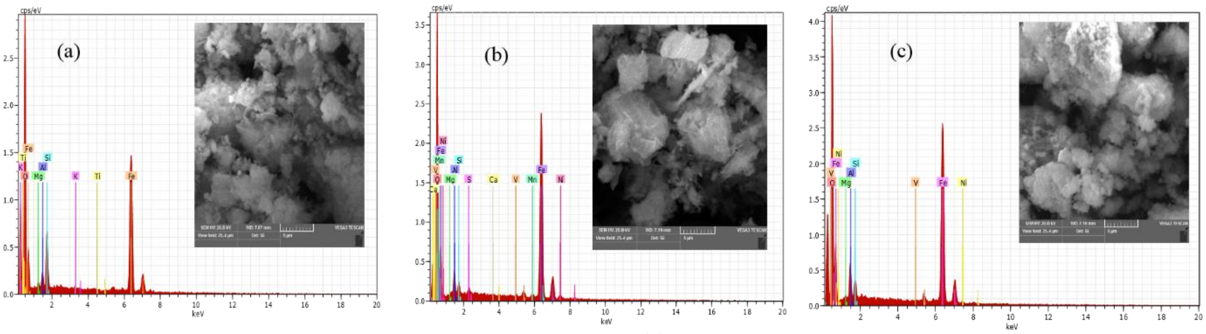

Fig. 3 EDAX spectrums and SEM microphotograph of ferro laterite soil (a) LH1, (b) LH2, (c) LH3

Mechanical characteristics test of ferro laterite soil, which the method for unconfined compressive strength test and CBR testing, in this case, brief results were obtained curing time for unconfined compressive strength are 3 days, 7 days, 14 days, and 28 days as shown in Fig. 4. The maximum density conditions for all soil types with different curing time showed an increasing trend, this was due to the bond between the grains in the soil more stable over time curing up to 28 days. It is seen that the increase in dry density from 1.73 to 1.99 tonnes / m3 with optimum moisture content decreased from 22.14 to 19.98%. The compressive strength of the soil also showed an increasing trend for all kinds of ferro laterite soil, increasing of soil density causing compressive strength increased from 69.98 to 73.20 kPa to LH1, 81.05 to 156.20 kPa for LH2, and 76,08- 80.01 kPa to LH3 as shown in Figure 4. Soil strength LH2 is higher than the two other typical soil, this is due to the condition of maximum density of micro pores become smaller and the bond between water and soil grains getting stronger, thus increasing soil density with increasing curing time lead to increased soil strength (Fig. 5).

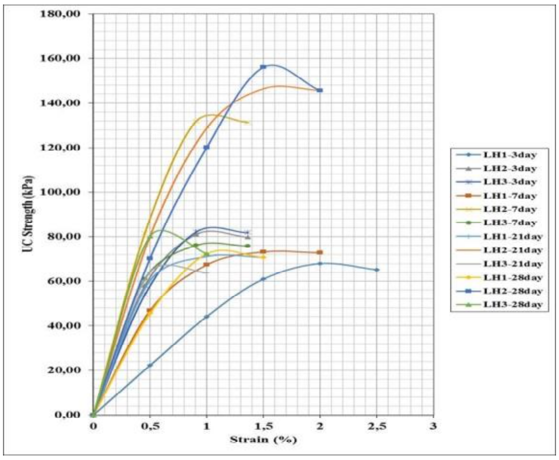

Fig. 4 Stress-strain curve of ferro laterite soil

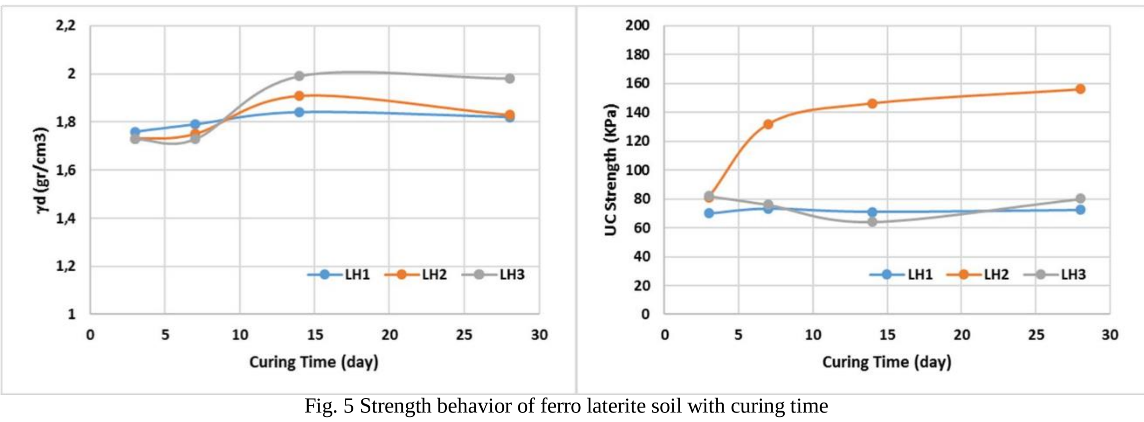

Fig. 5 Strength behavior of ferro laterite soil with curing time

Laboratory CBR testing carried out directly using a CBR test device. The result of the CBR and the interpretations are presented in Fig. 6, Fig. 7, and Table 5. For standard Proctor unsoaked, LH1 has 11,24% CBR, LH2 has 21,02% CBR, and LH3 has 12,33% CBR.

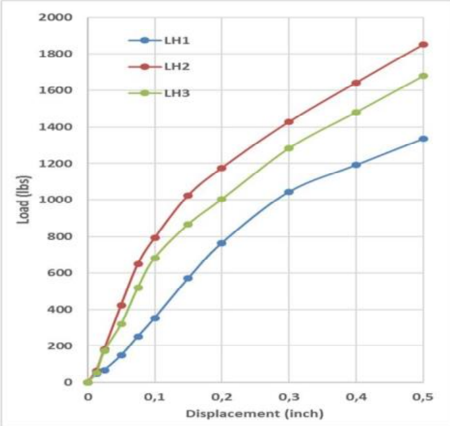

Fig. 6 CBR laboratory test of ferro laterite soil

Fig.7 shown that CBR laboratory of ferro laterite soil with increasing curing time. Based on the figure, the increase in curing time lead to an increase in the value of CBR but not significantly, especially for LH2 and LH3, this indicates that the increase in density and soil strength directly increase the bearing capacity of the soil. Soil with maximum density, due the volume of soil micro-pore be smaller, then particles bonding of clay mineral, especially montmorillonite were strong, therefore increasing the curing time caused the strength and bearing capacity of soil increased. Considering the value, they fall within the CBR value range 7-20% for LH1, and CBR value range 20-50% for LH2 and LH3 (Bowles, 1990). Hence, the soils could be useful for sub-base and sub-grade material for road construction.

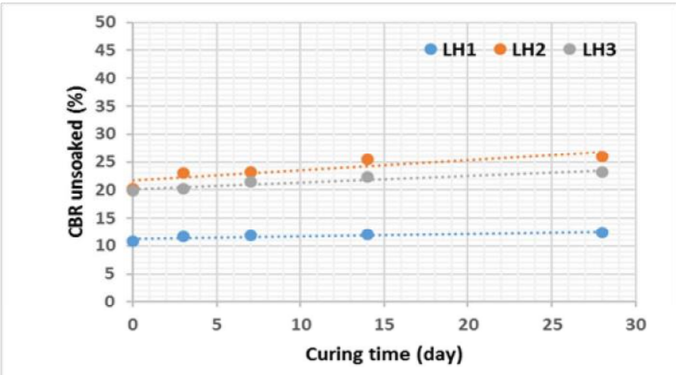

Fig. 7 Increasing CBR laboratory of ferro laterite soil with curing time

TABLE 5 - GENERAL RATING OF SOIL MATERIALS USING CBR VALUES (AFTER BOWLES, 1990)

CBR Value	General	Uses	Classification System
0-3	Verry poor	Sub-grade	OH,CH, MH, OL
3-7	Poor-fair	Sub-grade	OH, CH, MH, OL
7-20	Fair	Sub-grade	OL, CL, ML, SC, SM, SP
20-50	Good	Base, sub-grade	GM, GC, SW, SM, SP, GP
50	excelent	Base	GW, GM

IV. CONCLUSIONS

In this paper, three different ferro laterite soils related to the mechanical and microstructural characteristics for subbase material utilization was studied. The main aim was to determine and evaluated the characteristics and behavior of the mechanical and microstructural ferro laterite soil to be used as sub-base material. Based on physical properties, sample of the fare laterite soil was A-7-6 for AASHTO soil classification system and CH for USCS soil classification system.

The UCS data for curing time 28 day indicated a significant increasing strength of LH2, but not for LH1 and LH3. Also, it was found that the increase in density and soil strength directly increase the bearing capacity of the soil. The increase in curing time directly increasing the value of CBR but not significant, while based on CBR value the soils could be useful for sub-base and sub-grade material for road construction.

Ferro laterite soil it has the potential to be used as sub-base material, but need a detailed study on the possibility of increasing its ability with soil stabilization to give more confidence before used.

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