Study of Shear Strength Parameter of Lime Trass Stabilization on Clay: Ways to Improve Soil Strength

Qunik Wiqoyah and Anto Budi Listyawan *

Abstract: Clay soil is usually weak and has low shear strength because it contains many minerals that tend to be very high expansive. Expansive soils owe their characteristics to the presence of swelling clay minerals. As they get wet, the clay minerals absorb water molecules and expand; conversely, as they dry they shrink, leaving large voids in the soil. The problems arise when subgrade of highway pavement is made of expansive soil as it can be seen on Tanon, Sragen. The pavement damage is signed by cracking, settlement, and rutting. Tanon clay is classified as high plasticity inorganic clay (Wiqoyah, 2003). The Liquid Limit and Plasticity Index are 88.03% and 49.44% respectively. The cohesion and friction angle are 19.97 kg/cm2 and 2.140. The soil contains smectite clay minerals, such as montmorillonite, which exhibits the most profound swelling properties. Based on the last research on Tanon clay, the treatment should be carried out to improve the shear strength of the soil and to reduce all problems on the pavement. This research focuses to study the physical and mechanical characteristic of the Tanon clay mixed by lime and trass. The Tanon clay is mixed by lime and trass in the percentage of: 0%, 2.5%, 5%, 7.5% and 0%, 2.5%, 5%, 7.5%, 10% respectively. The mixed soil samples are tested in atterberg limit, gradation, specific gravity, and Unconsolidated-Undrained Triaxiall apparatus. The samples are in 3 days curing and 4 days soaking. The result shows that the lime and trass stabilization increases specific gravity, Plastic Limit and Shrinkage Limit. On the other hand, it reduces Liquid Limit and Plasticity Index. As the percentage of lime and trass increase, the friction angle tends to improve. The maximum friction angle occurs on the adding of both lime and trass of 7.5%. For 3 days of curing, the friction angle is 19.01o and for 4 days of soaking, it exhibits friction angle of 17.67o. The cohesion of Tanon clay stabilized by lime and trass also increases. The maximum cohesion of

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sample with 3 days curing occurs in the percentage of lime and trass of 7.5% and 2.5% respectively. On the other hand, the maximum cohesion of sample with 4 days soaking happens in the percentage pf lime and trass of 10% and 7.5% respectively. The simultaneous increasing of friction angle and cohesion show that the lime and trass stabilization on clay is effectively improving the soil strength.

Keywords: stabilization, clay, lime, trass, triaxiall.

I. Introduction

By and large, a pavement section consists of a relatively thin wearing surface (primarily made of asphalt or concrete), a base course, a sub-base course, and engineered subgrade. Thus, design of a pavement structure necessitates the material properties of aforementioned layers. The strength of subgrade takes an important role for determining the pavement thickness (flexible pavement). The high clayed subgrade should be considered as a weak soil. Thus, its physical and technical properties should be repaired due to the small shear strength and high sensitivity to the water content. The real problem is coming up for this particular soil as crack and rutting of the pavement begin to be a major damage. The pavement along the main road that connected the Solo city and Purwodadi in Central Java (i.e. Tanon Clay) was experienced those problems. The soil beneath the pavement of foundation layers was made of an expansive soil. Expansive soils, also known as swell-shrink soils, have been problematic for the civil infrastructures including roads and foundations (Nelson and Miller, 1992). Expansive soils swell and shrink with changes in moisture content. The current project for maintaining the damages is only focused to upper layers, so the root of the problem has not been solved yet.

According to Wiqoyah (2002), the Tanon Clay was classified as high plasticity an organic clay, with an Atterberg limit which is LL = 88.03%, PL = 38,58%, PI = 49,44%. The shear strength parameters are cohesion (c) = 19.97 kg/cm^2 and friction angle (□) = 2.14^0. Based on this preliminary research of Tanon Clay, the repairing and increasing of soil strength becomes an interesting manner. This research is focused on the lime and trass stabilization on Tanon Clay.

As a natural pozzolan, trass will bound with soil particle by forming calcium silicate as the result of its mixing with lime and water. In this current research, trass is taken from Matesih with the proportion of silica oxide, alumina oxides and ferro oxides less than 81% (Vulkanologi, 2002), so it meets the requirement of pozzolan in ASTM C 618-97-a for a minimal proportion of 70%.

A. Lime

Lime is described in the ASTM International Standards Worldwide (2006) as all classes of quicklime and hydrated lime, both calcite (high calcium) and dolomite (calcium and magnesium). In general, lime is used to stabilize soils with Plasticity Indices less than 20. It is chemically composed of calcium oxide (CaO) or calcium hydroxide ($Ca(OH)_2$). Lime has specific gravity of 0.48 to 1.2. The chemical process of quicklime can be described as follow (Tjokrodimuljo, 1992):

$$Ca + CO_3 \longrightarrow Ca\,O + CO_2 \quad (1)$$
$$CaO + H_2O \longrightarrow Ca(OH)_2 + heat \quad (2)$$
$$Ca(OH)_2 + CO_2 \longrightarrow CsaCO_3 + H_2O \quad (3)$$

The calcium hydroxide is more frequently used in stabilization of soil thane the calcium carbonate (CaCO3) that usually applied as filler (Ingles and Metcalf, 1992).

B. Trass

Trass is one of pozzolanic material which can be found in the Indonesian literature. Pozzolan is a natural or artificial material that consists of two main elements that are silica and alumina (ASTM C 618-92a). In the wet condition, it reacts with calcium hydroxide to form a cementious material. The composition of maximum oxides in a pozzolan can be seen on Table 1.

Table I. Chemical Composition of Pozzolan (ASTM C 618-92a)

Chemical composition		*Pozzolan class*		
		N	F	C
$Si_2O_3 + Al_2O_3 + Fe_2O_3$	minimum,%	70	70	50
SO_3	maximum,%	4	5	5
Water content	maximum,%	3	3	3
Burning loosing,	maximum,%	10	6	6

Pozzolan class N is made from natural stone, shale, tuff or volcanic ash. Pozzolan class F is man made material (fly ash) that meets the chemical and physical requirement. Pozzolan class C is the other material that can be used as pozzolan. In general, a natural pozzolan is divided into two types, which are naturally made and made from trees that have been burned in a certain temperature and time, so the ash is characterized as pozzolan. The reaction between wet pozzolan and lime will produce an insoluble cementious material (i.e. silicate hydrate).

C. Shear Strength of Soil

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. The shear strength parameter is needed to analyze bearing capacity of soil, slope stability and retaining structure. According to Hardiyatmo, 1999, the collapse of structure is due to the combination of critical normal and shear stress. Mohr stated the relationship between normal and shear stress in the equation of:

$$\tau = f(\sigma) \tag{4}$$

Coulomb, 1976 (in Hardiyatmo, 2000) defined $f(\sigma)$ as follow:

$$\tau = c + \sigma \, tg\varphi \tag{5}$$

where

τ : shear strength (kN /m^2)

c : cohesion (kN/m^2)

φ : friction angle (°)

σ : normal stress (kN/m^2)

II. Technical Work Preparation

In this current research, the soil is taken from Tanon, Sragen, Central Java, up to 1.0 m depth. The soil sample is in the disturbed condition. The soil mixed with lime in the variation of 0%, 2.5%, 5%, 7.5%, and trass in the variation of 0%, 2.5%, 5%, 7.5%, and 10%. The samples is tested in the laboratory with some testings (i.e. Specific Gravity, Water Content, seaving analysis and hydrometer, Atterberg limits, Standard Proctor Compaction test, Triaxial test in 3 days curing and 4 days soaking). A brief of the stage of the research can be illustrated as follow:

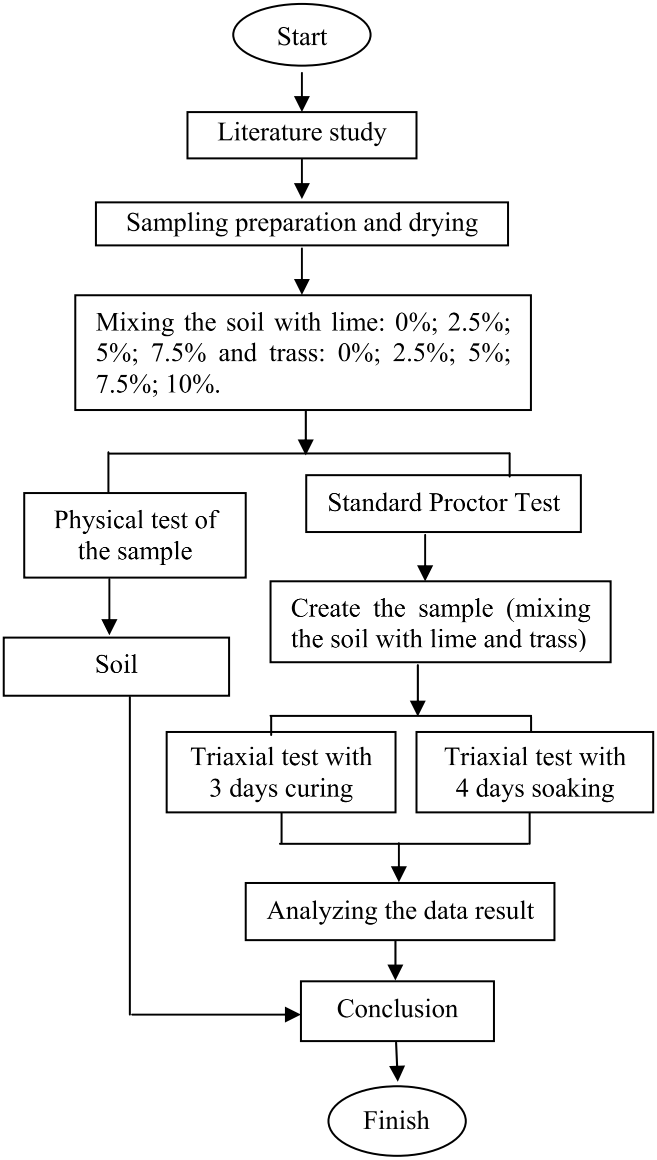

Fig. 1. Summary flowchart of technical work process

III. Result and Discussion

A. Physical Characteristic of Mix-soil

Specific Gravity

Figure 2 shows the increasing of specific gravity as the percentage of lime and trass increase. The high specific gravity of trass contributes this phenomenon. It is also due to the lesser ability of trass to flocculate that causes the mix soil having a smaller particle.

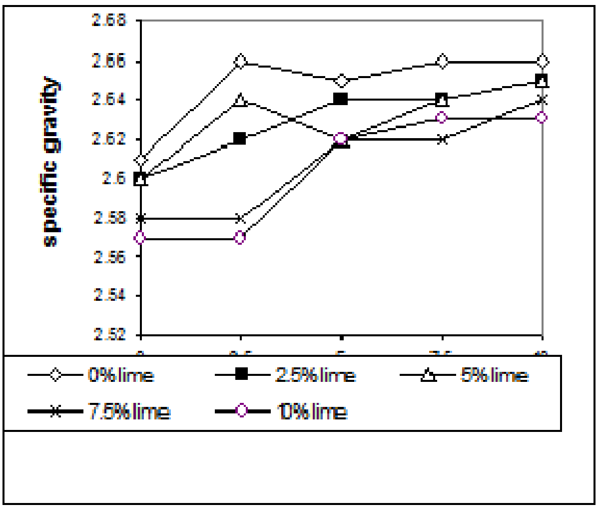

Fig. 2. The effect of lime and trass adding to the specific gravity of Tanon Clay

Atterberg limit

Liquid limit for mix-soil can be seen on Figure 3. The adding of lime and trass causes the appearance of cation in the water. It produces cation exchange between the soil particle, lime particle, and water in the void. As the result the cohesion decrease and causing the reduction of liquid limit (LL)

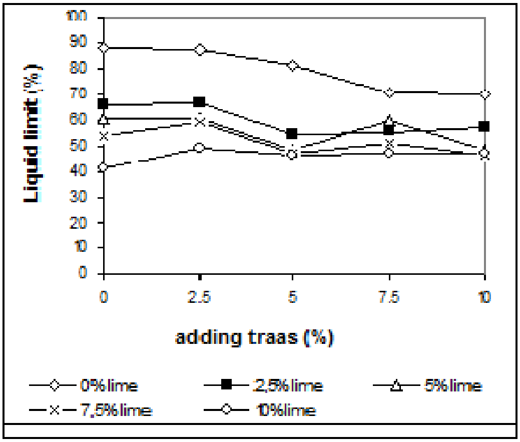

Fig. 3. The effect of lime and trass adding to the liquid limit of Tanon Clay

Since the cohesion drops, the plastic limit (PL) also declines as given in Figure 4. The flocculation process produces a new bigger soil particle and decreases the area of specific surface. It reduces the sensitivity of soil to the water effect and finally the shrinkage limit enlarges (Figure 5). As the effect of a decreasing liquid limit and an increasing plastic limit, the plasticity index drops, as given in Figure 6.

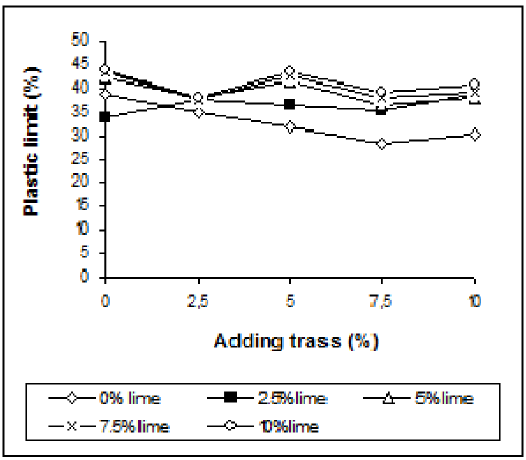

Fig. 4. The effect of lime and trass adding to the plastic limit of Tanon Clay

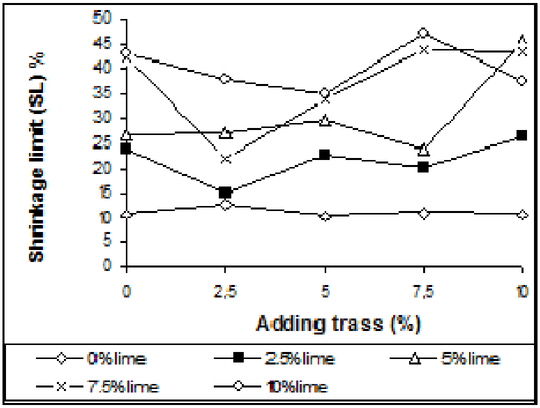

Fig. 5. The effect of lime and trass adding to the shrinkage limit of Tanon Clay

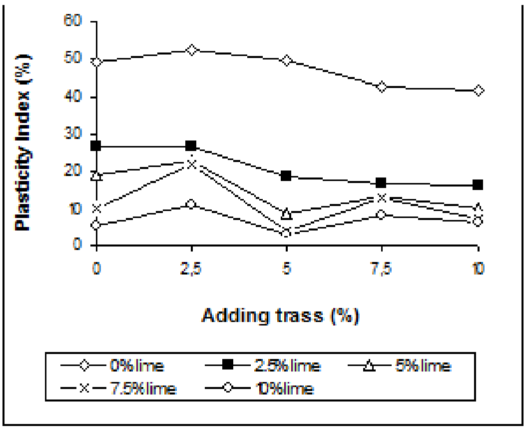

Fig. 6. The effect of lime and trass adding to the Plasticity Index of Tanon Clay

Particle gradation

The adding of lime and trass on Tanon Clay causes the change of fraction composition (i.e. the fraction < 0.075mm decreases) as illustrated in Figure 7. It makes the gradation vary and better than before. This is an evident that the cementation process occurs in the mixing soil with lime and trass.

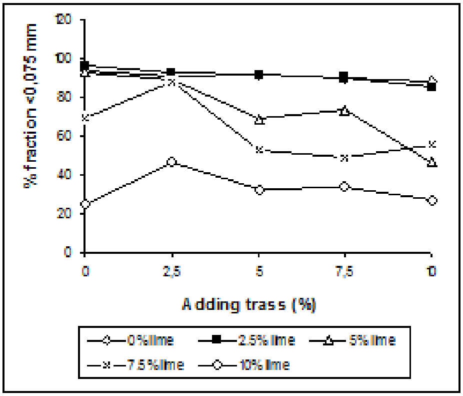

Fig. 7. The effect of lime and trass adding to the gradation of Tanon Clay

B. Mechanical Characteristics of Mix-soil

Standard Proctor Compaction

Figure 8 shows the adding of lime and trass making the dry density increases. It is a result of the gap between particle soils getting closer than former Tanon Clay. The trass fills the soils void and makes it denser. It is obvious, the void is getting smaller and decreases the volume of water filled. As a result, the optimum moisture content is getting smaller as well (Figure 9).

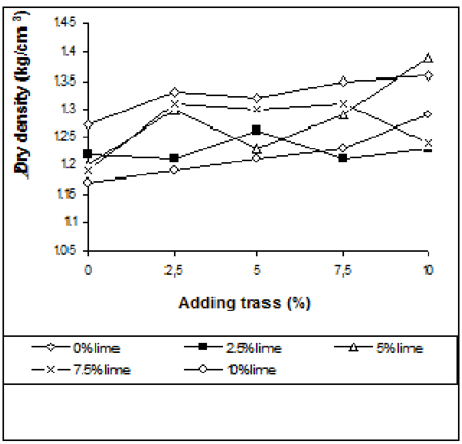

Fig. 8. The effect of lime and trass adding to dry density of Tanon Clay

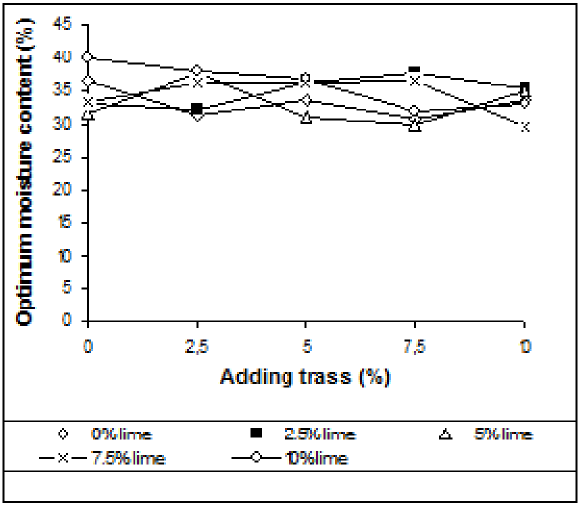

Fig. 9. The effect of lime and trass adding to the optimum moisture content of Tanon Clay

Shear strength parameter

The adding of lime and trass is effectively fixing the shear strength of Tanon Clay. An increasing of shear strength can be explained by the fact that the flocculation process as a logical effect of lime and trass stabilization produces a larger contact area (A_c) between soil particles. This process makes a large value of coefficient of soil friction and finally the friction angle also gets higher. The highest friction angle occurs in the adding of 7.5% lime and 7.5% trass either for 3 days curing or 4 days soaking (i.e. 19,01^o and 17,67^o respectively), as given in Figure 10 and Figure 11. In fact, the increasing of 3 days curing is higher than 4 days soaking. The 3 days curing gives more time to the flocculation process to reach its peak and form the bigger mass of soil. In 4 days soaking, the pore water pressure makes the bond on the particles weaker and the friction angle (φ) gets smaller.

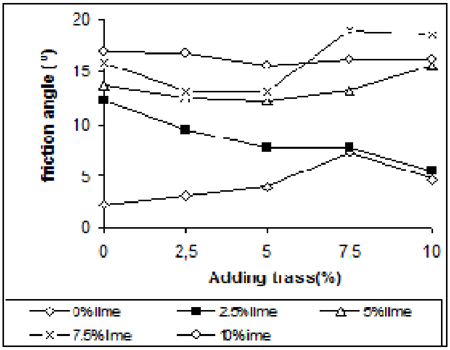

Fig. 10. The effect of lime and trass adding to friction angle of Tanon Clay (3 days curing)

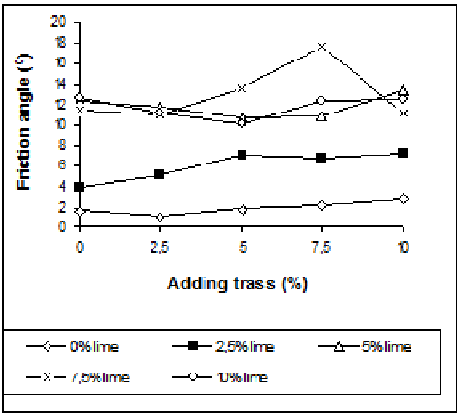

Fig. 11. The effect of lime and trass adding to friction angle of Tanon Clay (4 days soaking)

Figure 12 and Figure 13 show the increasing of cohesion (c) as the adding of lime and trass goes up. The maximum cohesion occurs in the adding of 7.5% lime and 2.5% trass for 3 days curing (i.e. 68.08 kg/cm^2). In 4 days soaking, the maximum cohesion appears in the adding of 10% lime and 7.5% trass (i.e. 45.88 kg/cm^2). The increasing of cohesion (c) arises due to the appearing of surface tension on the low saturated soil. The higher percentage of lime added, the lower the degree of saturation of soil, and the higher the cohesion. The 3 days curing more effectively increases the cohesion than 4 days soaking due to the lower degree saturation of soil appear in 3 days curing.

In contrast, some cohesions go down in a certain percentage added of lime and trass. It can be explained by the fact that in those certain mix-soil, the degree of saturation is increasing close to 100% or decreasing close to 0%.

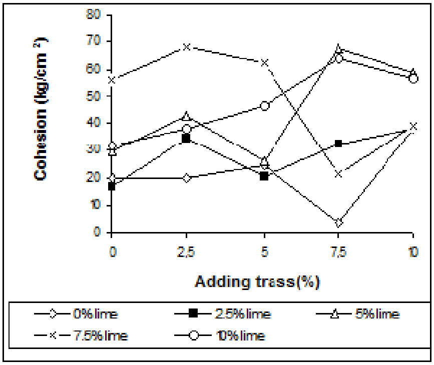

Fig. 12. The effect of lime and trass adding to cohesion of Tanon Clay (3 days curing)

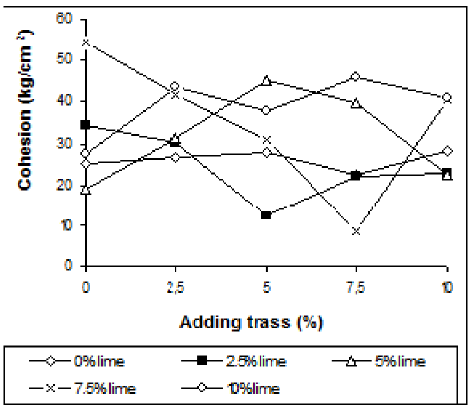

Fig. 13. The effect of lime and trass adding to cohesion of Tanon Clay (4 days soaking)

IV. Conclusion

The lime and trass stabilization to Tanon Clay affects the coil consistency. Its liquid limit and plasticity index go down to a maximum value of 41.3% and

46.15% respectively, but the plastic limit and shrinkage limit increase to a maximum value of 4.86% and 36.50% respectively.

The adding of lime and trass causes a number of particle restraints on the sheaving No. 200 (0.075mm) increasing or the finer particles decreasing. Moreover, the lime and trass reduce the specific gravity of Tanon Clay.

Obviously, the shear strength parameters of Tanon Clay are increasing due to the adding of lime and trass. The maximum increasing of friction angle (φ) and cohesion (c) for 3 days curing are 16.87^o and 48.61 kg/cm^2 respectively. For 4 days soaking, the friction angle (φ) and cohesion (c) increase to a maximum value of 16.06^o and 20.67 kg/cm^2 respectively. The maximum increasing of friction angle occurs for the adding of 7.5% lime and 7.5% trass for both 3 days curing and 4 days soaking. The maximum increasing of cohesion appears in the adding of 7.5% lime and 2.5% trass for 3 days curing, and 10% lime and 7.5% trass for 4 days soaking.

V. Acknowledgment

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VII. Biographies

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