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Research Paper

Modification Of Sidoarjo Lava Mud *("Lusi")* To Become Granular Material For Quality Fill Materials

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ABSTRACT

The term *LuSi* is abbreviation of ***Lu**mpur **Si**doarjo*, which is a certain type of hot lava mud coming out from the earth in *Sidoarjo*, East Java, Indonesia. The hot lava mud initially was outflowing at the rate about 100.000m^3/day and the flow peaked around 125.000m^3/day in 2007, but then gradually decreasing to become 20.000m^3/day up to now. *LuSi* contains of 88% fine materials with LL=81.58% and PI=49.56%; it is classified as CH or A-7-6. To reduce the volume of *LuSi*, it is planned to use as quality fill materials; it means that *LuSi* has to meet the fill material requirement. For this purpose, 10% of lime $Ca(OH)_2$ used as stabilization material and granulation process adopted to modify its particle size. The new material produced is non-plastic material called as granular lime-stabilized *LuSi* (SGL); its grain size is affected by rotation speed of granulator drum (V) during the granulation process. If SGL is compacted using compaction energy 90% of the maximum dry density (MDD), the minimum values of soaked CBR obtained are 7%, 12%, and 13% for V=6rpm, 8rpm, and 10rpm, respectively. It shows that SGL can be used at least as "regular fill material" because its minimum soaked CBR>6%.

1. Introduction

The term *LuSi* is abbreviation of ***Lu**mpur **Si**doarjo*, which is a certain type of hot lava mud coming out from the earth in *Sidoarjo*, East Java, Indonesia (Fig. 1). The mud outflow is believed to be caused by volcanic movement from the earth after oil exploration had accidently intruded into compressed mud layer deep under the ground and the earth (Tingay, *et al* 2008 and Davies, *et al* 2008). The occurrence of *LuSi* (at 2006) has been well known as *Sidoarjo* mud volcano disaster. The hot lava mud initially was outflowing at the rate about 100.000 m^3/day and the flow peaked around 125.000 m^3/day in 2007 but then gradually decreasing to become 20.000 m^3/day up to now. In 2009, the, *LuSi* had submerged about 850 hectares of land; in order to retain the *LuSi* from submerging wider area, 11.0 meters height of dike (embankment) was built surrounded the mud area (Fig. 2). The embankment, however, had undergone vertical displacement about 3.0 meters in seven years since 2006 (Agustawijaya, *et all* 2013 and Agustawijaya, *et all* 2014).

LuSi contains of 88% fine materials (clay fraction) and 12% fine to medium sand. The clay fraction is made of smectite clay mineral dominated by silica and alumina oxides to form book-house assemblage (Agustawijaya, *et all* 2017). Its liquid limit (LL) and plasticity index (IP) are 81.58% and 49.56%, respectively. In wet condition, *LuSi* is very sticky and lumpy to handle (BPLS, 2009). According to the Unified Soil Classification System, the initial-*LuSi* is classified as clay with high plasticity (CH) soil; and it is classified as A-7-6 (AASHTO).

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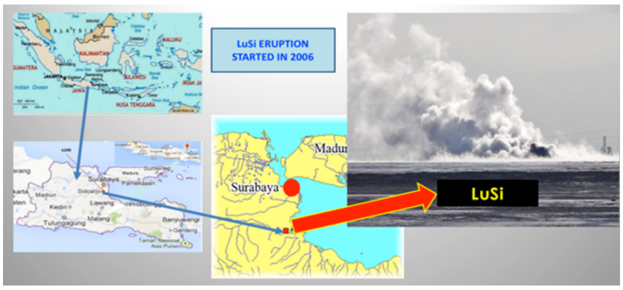

Fig. 1. Location of *Lumpur Sidoarjo* (*LuSi*) in *Porong, Sidoarjo*, East Java, Indonesia

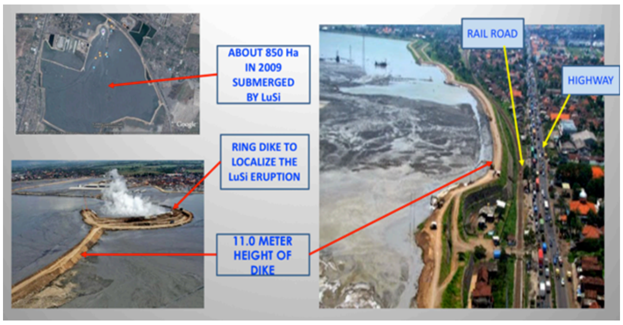

Fig. 2. Dike built surrounded the *Lumpur Sidoarjo (LuSi)* area

In order to reduce the volume of *LuSi*, many efforts had been done such as using it for brick, paving, cement substitution for concrete, etc.; these efforts, however, only reduce very little volume of *LuSi*. Because of that, in 2017 it was tried to use it as fill materials by modifying the grain size using the granulation process (Maliki, *et all* 2015). Parameters adopted for the granulation process were drum rotation speed (V) = 10 rpm, drum inclination angle (S) = 2.5°, water content (W_c) = 39%, and water temperature (T) = 25°C. The result shows that the granulation process is able to produce granular size of *LuSi* (GL) as shown in Fig. 3; it is classified as well graded sand (SW). The soil grains, however, are melting when it is soaked in the water. GL has to be water resistance and low plasticity and in order to meet the requirement of fill material that is PI<10% and soaked CBR>6% (for "regular fill material") and its PI<6% and soaked CBR>10% (for "quality fill material") (Kemenpupr Bina Marga, 2010).

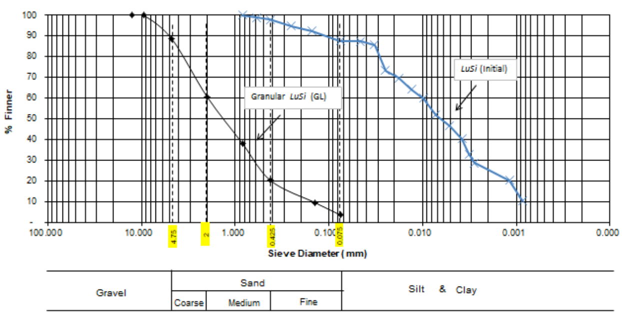

Fig. 3. Grain size distribution curves of LuSi (initial) and granular size of LuSi (GL) produced by granulation process

In order to reduce its plasticity and to make the granular size of *LuSi* (GL) is water resistance materials, 10% of lime $Ca(OH)_2$ as stabilization materials (Faizah and N.E Mochtar, 2013) is mixed with *LuSi* (initial) and then granulation process was adopted to modify its particle size. The new material produced is non-plastic material, called as granular size of lime-stabilized *LuSi* (SGL), was then cured in 20 days. The grain particles produced is mainly depending on the rotation speed of granulator drum (V) during the granulation process (Pasmar, *et all* 2018); other parameters (drum inclination angle, water content, and water temperature) slightly affects the grain size during granulation process. This paper will present how to prepare *LuSi* (initial) to be granular size of lime-stabilized *LuSi* (SGL) that able to fulfill the fill materials requirements; these are:

- how the rotation speed of the granulator drum (V) affect the grain size distribution of SGL produced;
- how the compaction energy affects the maximum dry density (MDD) and maximum value of soaked CBR of SGL; and
- what is the minimum value of soaked CBR achieved at different compaction effort 90%, 95%, 100% of MDD.

2. Material and Methodology

Materials used in this study were *LuSi* (initial) and lime $Ca(OH)_2$. *LuSi* was stabilized with 10% lime $Ca(OH)_2$ in order to reduce its plasticity and to make it water resistance. The lime-stabilized *LuSi* was then granulated by using granulation process to prepare the granular size of lime-stabilized *LuSi* (SGL) as materials studied. In this study, the parameters chosen for granulation process were as follows:

- rotation speed of granulator drum (V) = 6 rpm, 8 rpm, and 10 rpm
- inclination angle of granulator drum (S) = 5°
- water temperature (T) during the granulation process = 25°C
- water content (Wc) of the granular size of lime-stabilized *LuSi* = 39%

As mention previously that the granular size of lime-stabilized *LuSi* (SGL) produced by granulation process was cured for 20 days. Afterwards, the compaction test was carried out to determine the maximum dry density (MDD) and its optimum water content. The soaked CBR determined from the same 3 (three) samples as used for compaction test; samples for CBR test were soaked for 7 days. Afterwards, CBR test was carried out to determine soaked CBR value. From the compaction and CBR curves of SGL obtained, curve of (Υ_d vs soaked CBR) was able to be constructed. From that curves, the minimum values of soaked CBR that could be achieved by SGL were determined by adopting the "*fifteen point methods*" (The Asphalt Institute, 1969).

3. Results and Analysis

3.1 The effect of rotation speed of granulator drum (V) to grain size distribution of SGL

As mention previously that granulation process was carried out at different rotation speed of granulator drum (V): 6 rpm, 8 rpm, and 10 rpm; other parameters, inclination angle of granulator drum (S), water content (Wc), and water temperature (T) were kept the same. The grain size distribution curves produced by granulation process with different rotation speed of granulator drum (V) are plotted in Figure 4; the percentages of gravel, sand, fine materials of *LuSi* (initial) and SGL produced by different 'V' are given in Table 1. At 'V' = 6 rpm, SGL is dominated by gravel; at higher V=10rpm, more medium size of sand is produced. It shows that with lower rotation speed of granulator drum (V), the materials have longer time to make soil layer to produce bigger size of soil particles. From Fig. 4 and Table 1, it is confirmed that by using granulation process the grain size of lime-stabilized *LuSi* (SGL) can be modified satisfactorily.

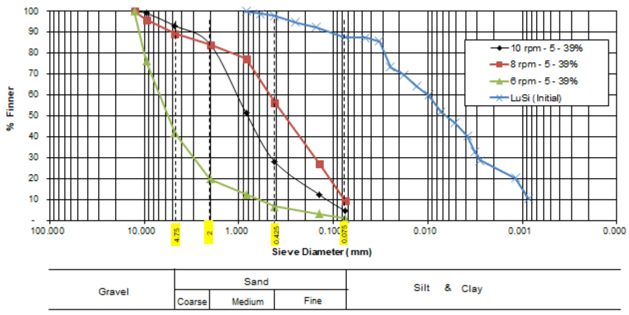

Fig. 4. Grain size distribution curve of *LuSi* (initial) and SGL produced by granulation process at different speed of granulator drum (V) = 6rpm, 8rpm, and 10rpm.

Table 1. The Percentages of Gravel, Sand, Fine Materials of *LuSi* (initial) and SGL Produced by Granulation Process with Different Rotation Speed of Granulator Drum (6rpm, 8rpm, and 10rpm) and Their Soil Classification

SOIL PARTICLES	UNIT	*LUSI* (INITIAL)	GRANULAR SIZE OF LIME-STABILIZED *LUSI* (SGL)		
			V=6 rpm	V=8 rpm	V=10 rpm
Gravel	%	-	58.42	10.65	6.8
Coarse Sand	%	-	22.11	5.33	8.96
Medium Sand	%	4	12.91	27.52	55.84
Fine Sand	%	8	5.89	46.61	23.7
Silt + Clay	%	88	0.67	9.89	4.7
SOIL COEFFICIENT					
Cu (Uniformity Coef)		-	10,77	6,45	8,46
Cc (Gradation Coef)		-	2,32	0,73	1,42
% Passing Sieve # 200		88	0.67	9.89	4.7
Soil Classification (USCS)		CH	GW	SP-SM	SW

Note : GW: well graded gravel, SW: well graded sand, SP-SM: poorly graded sand with silt

In order to classify the SGL produced by granulation process using different rotation speed 'V', two parameters uniformity coefficient (Cu) and gradation coefficient (Cc) are determined as given in Table 1. Based on those two parameters and percentage of particles passing sieve no 200, the SGL produced with rotation speed 'V': 6rpm, 8rpm, and 10rpm, can be classified as well graded gravel (GW), poorly graded sand with silt (SP-SM), and well graded sand (SW), respectively. It shows that SGL produced by the same granulation process but using different rotation speed of granulator drum V can give different grain size of soils and their soil classification.

3.2 The effect of compaction energy to the maximum dry density (MDD) and soaked CBR of the granular size of lime-stabilized LuSi (SGL)

In this study, energy used for compaction was 13 blows/layer, 27 blows/layer, and 56 blows/layer that were comparable to 90%, 95%, 100% energy used for modified Proctor compaction test, respectively. The compaction curve of granular size of lime-stabilized *LuSi* (SGL) compacted at different energy are given in Fig. 5; the curves given are for SGL produced by granulator drum at rotation speed (V) 10 rpm, inclination angle 5°, and water content 39% (10rpm-5°-39%). The effect of compaction energy to maximum dry density (MDD) and water content optimum ($W_{c\text{-}opt}$) are given in Fig. 6. They show that the higher the compaction energy used, the higher the maximum dry density (MDD) achieved and the lower the $W_{c\text{-}opt}$ obtained. The effect of energy used (from 13 blows/layer to the 27 blows/layer) to the MDD is not really significant; from 27 blows/layer to the 56 blows/layer, however, it causes significant increment of MDD. The increment of compaction energy used is in linear relation with the decrement of Wc_{opt}.

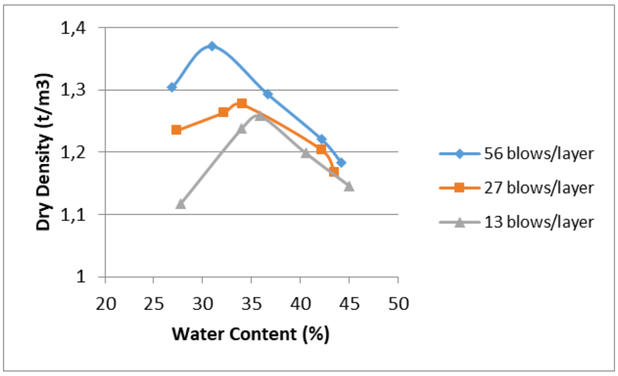

Fig. 5. Compaction curves of SGL produced granulation process with rotation speed of granulator drum 10rpm, inclination angle 5°, water content 39% (10rpm-5°-39%) compacted at different energy.

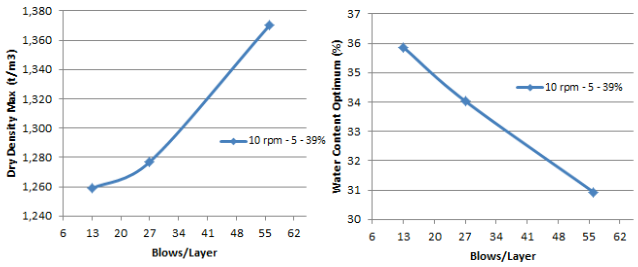

Fig. 6. The effect of compaction energy to the maximum dry density (MDD) and water content optimum ($W_{c\text{-}opt}$) of SGL produced by granulation process with (10rpm-5°-39%)

The CBR test results for the same SGL tested for compaction test are plotted in Fig. 7; the effect of compaction energy applied to the soaked CBR value is given in Fig. 8. They show that the maximum soaked CBR value reached at different water content depending on the compaction energy applied. The soaked CBR vs W_c curves have similar behavior with the compaction curves where the higher compaction energy applied, the higher the soaked CBR value obtained. The increment value of soaked CBR produced by soil compacted from 13 blows/layer to 27 blows/layer is more significant than the one compacted from 27 blows/layer to the 56 blows/layer.

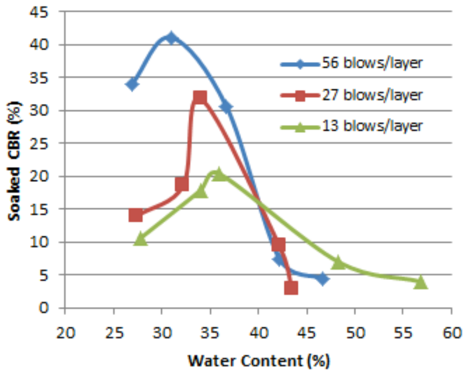

Fig. 7. CBR curves of SGL produced by granulation process with rotation speed of granulator drum 10rpm, inclination angle 5°, water content 39% (10rpm-5°-39%) compacted at different energy.

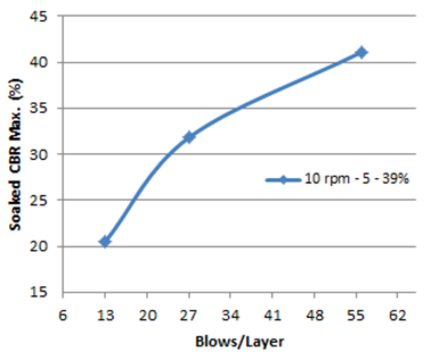

Fig. 8. The effect of compaction energy to the maximum soaked CBR of SGL produced by granulation process with (10rpm-5°-39%)

3.3 The minimum value of soaked CBR achieved by SGL at different compaction effort

Soaked CBR minimum can be determined by adopting *the Fifteen Point* Method. For this purpose, water content at range of $W_{c\text{-}opt}$ ± 1.50% is chosen; in that range, 4 (four) different values of water content (Wc) are determined. For SGL produced by granulator drum at rotation speed (V) 10 rpm, the range of $W_{c\text{-}opt}$ ± 1.50% is 29.50% - 37.50%; 4 (four) values of water content chosen in that range are 29.50%, 32%, 35%, and 37.50%. Through those 4 (four) values of water content chosen, draw 4 (four) lines until intersect the compaction and soaked CBR curves as shown in Fig. 9. From the intersection between those four lines and the curves, values of dry density and the soak CBR at the same water content (W_c) can be determined. Afterwards, those values are plotted to construct curves that have relationship between dry density and soak CBR as shown in Fig. 10.

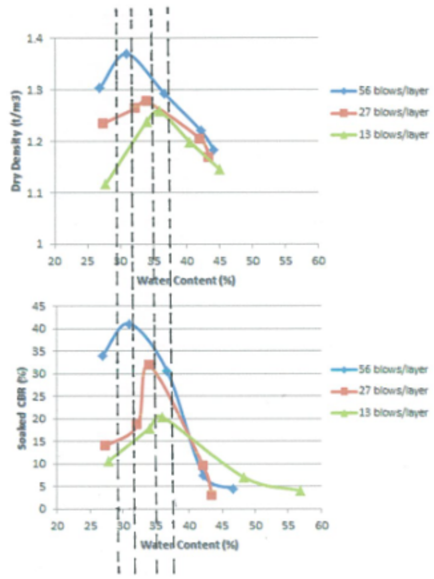

Fig. 9. Application of the fifteen point method to determine the values of dry density (Υ_d) and soaked CBR at the same water content W_c

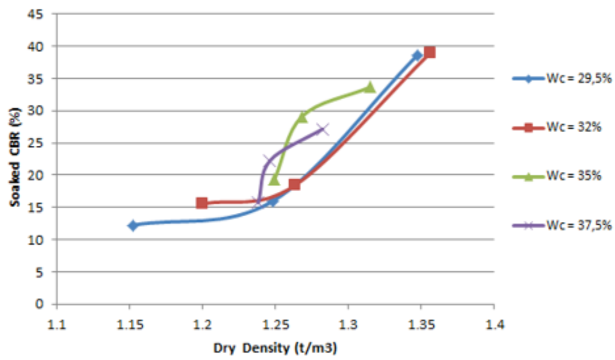

Fig. 10. Relationship between dry density (Υ_d) and soaked CBR values at water content 29.50%, 32%, 35%, and 37.50% for SGL produced by granulation process with V=10 rpm, S=5^0, and W_c=39%, (10rpm-5°-39%)

In order to determine the soaked CBR minimum that can be achieved by different compaction energy, three lines related to 90%, 95%, 100% of maximum dry density (MDD) are plotted at curves (Υ_d vs soaked CBR) in Fig. 11. From intersection between the lines and those curves, the minimum CBR value that can be achieved by using 90%, 95%, 100% of maximum dry density (MDD) are 13%, 23%, and 39%, respectively, for SGL produced by (10rpm-5°-39%). By using the same method, the minimum soaked CBR value that can be achieved by SGL that produced using V= 6 rpm and 8 rpm are given in Table 4. The minimum soaked CBR value that can be achieved by using 90% of maximum dry density (MDD) is 7%, 12%, and 13% when the rotation speed of granulator drum is 6 rpm, 8rpm, and 10rpm, respectively. It shows that for the same compaction energy applied, the minimum value of soaked CBR increases with the increase of granulator drum speed.

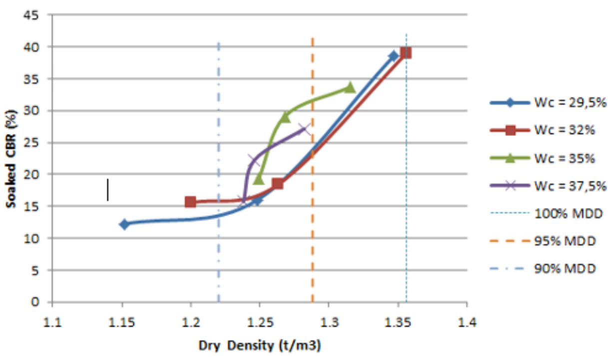

Fig. 11. Three lines draw through 90%, 95%, and 100% of maximum dry density (MDD) to determine the minimum soaked CBR of SGL produced by granulation process with V=10 rpm, S=5^0, and W_c=39%, (10rpm-5°-39%)

From the result above, it is known that by mixing 10% of of lime $Ca(OH)_2$ as stabilization material and by using the granulation process for modifying the grain size of *LuSi* (initial), the non-plastic granular size of lime-stabilized *LuSi* (SGL) produced is able to fulfill the requirement at least for "regular fill material" (minimum soaked CBR>6%) when the SGL produced by granulation process with V = 6 rpm and compacted with 90% MDD. In the other hand, the others SGL produced by granulation process with V = 8 rpm and 10 rpm are able to fulfill as "quality fill material" (minimum soaked CBR>10%) although they are compacted with 90% MDD.

Table 2. The Minimum Values of Soaked CBR Achieved by SGL (Produced with V=6rpm, 8rpm, and 10rpm) Using Compaction Energy 90%, 95%, and 100% of Maximum Dry Density (MDD).

Rotation Speed of Granulator Drum (V)	Unit	Minimum Soaked CBR Values		
		90% MDD	95% MDD	100% MDD
6rpm	%	7	17	20
8 rpm	%	12	22	32
10 rpm	%	13	23	39

4. Conclusion

From the discussion and analysis given above, it can be concluded as follows:

a. *LuSi* (initial) contains of 88% fines materials with LL=81.58% and PI=49.56%; it is classified as CH or A-7-6;
b. Granulation process successfully modifies the fine material of *LuSi* (initial) to be granular materials (GL); the fine material of LuSi, however, has to be stabilized with 10% of lime $Ca(OH)_2$ before granulation process in order to make GL water resistance and reducing its plasticity. The stabilized GL is called as the granular size of lime-stabilized *LuSi* (SGL).
c. Rotation speed of granulator drum (V) affects the SGL produced; for V=6rpm, 8rpm, and 10rpm, the SGL produced are classified as (GW), (SP-SM), and (SW), respectively.
d. Increment of compaction energy causes the increment of maximum dry density (MDD), the decrement of water content optimum ($W_{c\text{-}opt}$), and the increment of soaked CBR of SGL. If the compaction energy applied is 90% of maximum dry density (MDD), the minimum values of soaked CBR achieved are 7%, 12%, and 13% for V= 6rpm, 8rpm, and 10rpm, respectively. At the highest compaction energy applied (100% MDD), the minimum values of soaked CBR achieved are 20%, 32%, and 39% for V= 6rpm, 8rpm, and 10rpm, respectively,
e. The granular size of lime-stabilized *LuSi* (SGL) at least can be used as "regular fill materials" (minimum soaked CBR>6%), if *LuSi* (initial) is:
   - mixed with 10% of lime $Ca(OH)_2$ as stabilization material,
   - modified its grain size using granulation process with minimum rotation speed of granulator drum V = 6 rpm, and
   - compacted using compaction energy 90% of maximum dry density (MDD).

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