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Improvement in Properties of Expansive Clay by Stabilizing with Buton Rock Asphalt

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Graphical abstract

Abstract

Subgrade is a soil layer underneath a constructed road pavement, airport runway or railway track. It is essential to make the layer stable and has sufficient shearing strength to withstand the traffic induced stresses without excessive deformation. If the subgrade soil is weak, it may need to be stabilized to improve its properties. This paper investigates the suitability of Buton Rock Asphalt (BRA) and natural sand in stabilizing expansive clay in order to be used as subgrade soil. Amount of 2%, 4%, 6%, and 8% of BRA by weight of soil were added while 5 to 25% of natural sand in increments of 5% by weight of soil was added to compare the effects of using natural sand and BRA in stabilizing expansive clay. Tests such as Atteberg Limit, California Bearing Ratio, and direct shear were conducted on both natural clay soil and clay stabilized BRA. From the study, it was found that BRA can improve bearing capacity of expansive clay soil better than the natural sand.

Keywords: Buton Rock Asphalt, stabilizer, expansive soil, bearing capacity, strength.

1.0 INTRODUCTION

Soil is one of nature's most abundant construction materials. Almost all construction is built with or upon soil. When unsuitable construction conditions are encountered, the following four options can be selected to be conducted: a) Find a new construction site; b) Redesign the structure so it can be constructed on the poor soil; c) Remove the poor soil and replace it with good soil; d) Improve the engineering properties of the site soil. Option d is being used more often today and is expected to dramatically increase in the future [1].

Improving on-site (in-situ) soil's engineering properties is referred to as either "soil modification" or "soil stabilization" The term "modification" implies a minor change in the properties of soil, while stabilization means that the engineering properties of the soil have been changed enough to allow field construction to take place.

Soil stabilization, which every civil engineer is concerned with, is closely associated to the structures and mineralogy of the clay particles, clay-water interactions, clay particles' ionic exchange capacity and the clay organic or clay-inorganic interaction. The majority of road failures are associated with the action of water, or perhaps more precisely, the interaction between water and the clay particles under the road pavement [2, 3].

1.1 Objectives Of The Research

The objectives of this research are to stabilize expansive clay soil, the subgrade soil of Semarang – Purwodadi road and investigate the suitability of Buton Rock Asphalt (BRA) as a soil stabilizer.

2.0 LITERATURE REVIEW

There are two primary methods of soil stabilization used today, namely mechanical and chemical or additive method. The most common form of "mechanical" soil stabilization is a compaction of soil, while the addition of cement, lime, bituminous, or other agents are referred to as a "chemical" or "additive" method of soil stabilization.

Two basic types of additive used during chemical soil stabilization: mechanical additives and chemical additives [4].

Mechanical additives such as soil cement, mechanically alter the soil by adding a quantity of material that has the engineering characteristics to upgrade the load-bearing capacity of the existing soil. Chemical additives such as lime, chemically alter the soil itself, thereby improving the load-bearing capacity of the soil.

2.1 Mechanics of Stabilization

The various types of stabilization have been categorized according to the properties imparted to the soil. Types of admixtures include cementing agents, modifiers, waterproofing agents, water-retaining agents, water-retarding agents, and miscellaneous chemicals. The behavior of each of these admixtures is vastly different from the others; each has its particular use, and, conversely, each has its own limitations.

The principal cementing materials that may be used include Portland cement, lime, lime-fly ash mixtures and bitumen. Portland cement has been used with great success to improve existing gravel roads, as well as to stabilize natural soils. It can be used for base courses and sub-bases of all types. It can be used in granular soils, silty soils, and lean clays, but it cannot be used in organic materials. Since soil cement shows strength gains over that of the natural material, it is very often used for base-course construction [5, 6].

Another cementing agent, which is often used, is hydrated lime. Lime increases soil strength primarily by pozzolanic action, which is the formation of cementitious silicates and aluminates. This material is most efficient when used in granular materials and lean clays, the quantity required for proper hydration generally is relatively low.

Fly ash is generally high in silica and alumina; therefore, the addition of fly ash to lime stabilized soil speeds the pozzolanic action [6]. However, the quantity of fly ash required for adequate stabilization is relatively high, restricting its use to areas that have available large quantities of fly ash at relatively low cost.

Occasionally, the use of a cementing material is restricted because of cost, and, therefore, low quantities of the material may be added to the soil merely to modify it. Modifiers that are often used include cement, lime, and bitumen. Cement and lime change the water film on the soil particles, modify the clay minerals to some extent, and decrease the soils plasticity index. Small amounts of bituminous materials are very often used in low-grade aggregates, where the function of the bituminous material is to retard moisture sorption of the clay fraction of the soil-aggregate mixture. These modifying materials are generally best adapted to use in borderline base-course materials.

The next category of stabilization includes the waterproofing materials. Foremost among these are bituminous materials, which coat the soil or aggregate grains and retard or completely stop sorption of moisture. Bituminous stabilization is best suited for semi-granular soils. Retarding or stopping moisture movement into soil can also be accomplished by enveloping the soil in an asphaltic or plastic membrane.

2.2 Chemical Stabilization

Some chemicals increase rate of water sorption. They include calcium chloride and sodium chloride. These materials lower the vapor pressure of soil water and lower the freezing point of the soil water as well. Thus, they can be used as a construction expedient to retard evaporation of the soil water during compaction or, in some cases, to prevent freezing of the soil water [7].

Many other chemicals are available for stabilization. They include compounds that will render a soil hydrophobic. These chemicals will decrease rate of water sorption to a minor extent but, in general, are very costly, thus limiting their widespread use.

2.3 Buton Rock Asphalt

BRA is the natural asphalt discovered in Buton Island located in South-East Sulawesi, Indonesia. The areas in Buton Island which have much deposit of rock asphalt are Lawele, Kabungka, Waisnu, Wariti, and Epe. Based on the five study areas, Lawele and Kabungka have the most rock asphalt. Natural rock asphalt was found firstly in 1926 by Hetzel, a Dutch geologist. Survey conducted by Ministry of Energy and Mineral Resources Republic of Indonesia show that deposit of natural rock asphalt are estimated around 650 to 700 million tones [8]. Deposit of rock asphalt can only be found in 1 to 1.5 meter depth from the land surface as shown in the Fig. 1, and the bitumen content found in the rock, asphalt range is within 10 and 40%. Since the time of its discovery, out of 700 million tones deposits of BRA, only 3.4 million has been explored.

For this research, BRA was supplied by Buton Aspal Indonesia (BAI) Co. Ltd in form of coarse grain and was packed in bag contains 25kg per bag (Fig. 2). BAI Co. Ltd. takes BRA from Lawelle quarry. Gradation of BRA and it other properties are shown in Table 1.

Figure 1 Rock asphalt in Lawelle quarry of Buton Island [8]

■3.0 RESEARCH METHODOLOGY

This research was conducted in the Geotechnical Laboratory, Faculty of Engineering, Universitas Islam Sultan Agung (UNISSULA) of Semarang, Indonesia. Soil to be stabilized was expansive clay soil obtained from the subgrade of Semarang-Purwodadi road, which is 64 km length of provincial road located in North-East Central Java Province of Indonesia.

For the comparison purposes, stabilized soil with BRA was then compared with another natural stabilizer which was sand. Atterberg limit, California Bearing Ratio, Direct Shear tests had been conducted in order to assess the strength and properties of soil after being added with the stabilizer material. Amount of 2, 4, 6, and 8% of BRA and 5, 10, 15, 20, and 25% of natural sand by weight of soil were added

Figure 2 BRA in bag (left) and coarse grains of BRA (right) [8].

Table 1 Gradation and properties of BRA [8].

No.	Test	Test Method	Result	Specification	Unit
1	Gradation: Sieve No. 16 Sieve No. 30 Sieve No. 50 Sieve No. 100 Sieve No. 200	ASTM C-136	 100 54.02 16.97 3.75 1.82		 % passing % passing % passing % passing % passing
2	Bitumen content	ASTM D-1586	22.52	16 - 22	%
3	Solubility in C_2HCl_3	ASTM D-2042	18.72	Minimum 18	-
4	Specific gravity	ASTM D-854	1.976	1.70 – 1.90	-
5	Flash point	ASTM D-9272	232	Minimum 230	^0C
6	Water content	ASTM D-1461	0.81	Maximum 1	%
7	Volatile content by distillation	ASTM D-402	0.20	-	%

■4.0 LABORATORY EXPERIMENTS

4.1 Expansive soil

Laboratory experiments were performed to classify the natural expansive clay soil. Table 2 display the results of Atterberg Limit test which indicates that the Plasticity Index (PI) value is 33.9% is categorized high, and the soil can be classified as expansive clay.

Table 2 The results of Atterberg limit test for expansive soil

Test	Result
Liquid Limit (LL)	75.9%
Plastic Limit (PL)	42%
Plasticity Index (PI) = LL - PL	= (75.9 – 42)% = 33.9%

4.2 Mix soil with BRA

Laboratory works of Soil–BRA stabilization was commenced by activating bitumen that contain in the BRA in order to be able to blend with soil. Activated bitumen in the BRA was conducted by adding bunker oil. Bunker oil that was used in ship lubricating oil was added and mixed to BRA and then kept in a shady place for 48 hours. After 48 hours, bitumen in the BRA will melt, and the particles of BRA become soft. An amount of 2, 4, 6, and 8% of this melting BRA were then added to the soil used as stabilizer. Atterberg limit, CBR, and direct shear test were performed on the mixtures of soil-BRA and soil-sand.

■5.0 RESULTS AND ANALYSIS

5.1 Soil-BRA stabilization

5.1.1 Atterberg Limit

The Atterberg test results are given in Fig. 3. It shows that the values of Plasticity Index (PI) decreased by increasing the BRA content in the soil. These results correspond to the directional hypotheses that the lower PI value, the less potential of soil to become expansive. This means that by adding more BRA the soil will become less expansive. Decreasing of PI value was caused by reducing of pores in the soil and was filled with BRA.

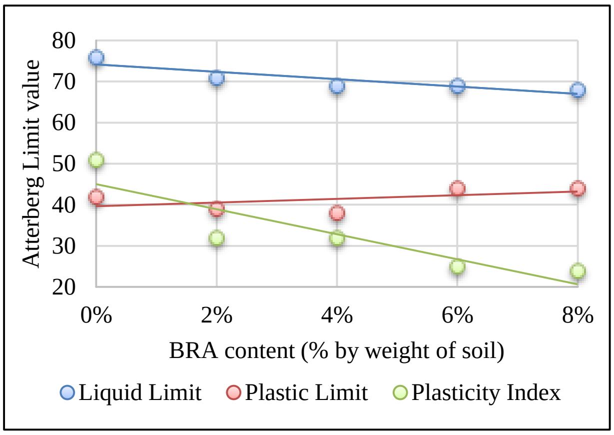

Figure 3 Atterberg limit values of soil-BRA mixture

5.1.2 California Bearing Ratio (CBR) Test

The results of CBR test for BRA stabilize expansive soil are illustrated in Fig. 4. The result shows that by adding more BRA content, the higher the CBR value is. Regression model give coefficient of determination, R^2 = 0.923 and coefficient of correlation, R = 0.9610, and shows that between BRA content and CBR have strong correlation, where the contribution of BRA to CBR value is above 90%. It can be concluded that the CBR value of soil-BRA is also fit with the directional hypotheses CBR values of BRA stabilized soil also have linear line with line equation y = 51.45x + 2.126. Using that equation, if the BRA content is added 20%, the CBR value will become 12.43% andshould be suitable for subgrade material.

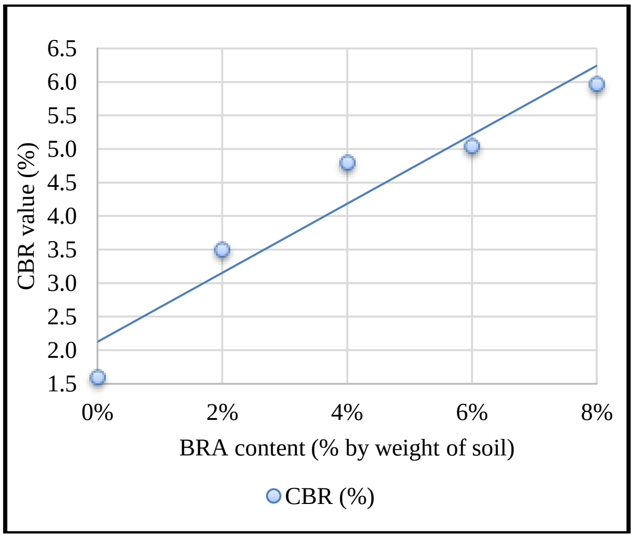

Figure 4 CBR values of soil-BRA mixture

5.1.3 Swelling Potential

To correlate common soil tests with swelling potential, Holtz and Gibbs used Plasticity Index (PI) and Liquid Limits (LL), while Chen, used only LL [9]. Holtz and Gibbs as well as Chen divided swelling potential into four groups, low, medium, high, and very high. Tables 3 and 4 show the correlations with common soil tests to determine swelling potential conducted by Holtz and Gibbs, and Chen respectively [9].

Table 3 Correlations with common tests by Holtz and Gibbs [5]

PI	Shrinkage Limit	LL	Swelling Potential
< 18	< 15	< 39	Low
15 – 28	10 – 16	39 – 50	Medium
25 – 41	7 – 12	50 – 63	High
> 35	> 11	> 63	Very High

Table 4 Correlations with common tests by Chen [9]

LL	Probable Expansion	Swelling Pressure (kPa)	Swelling Potential
< 30	< 1	50	Low
30 – 40	1 – 5	150 – 250	Medium
40 – 60	3 – 10	250 – 1000	High
> 60	> 10	> 1000	Very High

From both tables of correlation, and the Atterberg Limit test results of soil-BRA and soil-sand, it is shown that the swelling potential for soil after stabilizing with BRA or sand is still very high.

5.1.4 Direct Shear Test

The results of direct shear test of BRA stabilized soil are given in Fig. 5 and Fig. 6 for cohesion value and angle of internal friction Ø respectively. Attention should be paid to this direct shear test results. Normally, the higher cohesion value of soil, the lower value of Ø. However, soil-stabilized with BRA shows different results. The values of cohesion and angle of internal friction were higher. That result can be explained as follows: when BRA was added and thoroughly blend to the soil, all particles of soil will be bind by melt bitumen of BRA and make the mix of soil-BRA becomes cohesive. Nevertheless, this cohesion is false cohesion, since the BRA contains rock particles, thus, the soil mixtures are clotted, hard and granular. In view of this, the angle of internal friction increases with increase in the percentage of BRA.

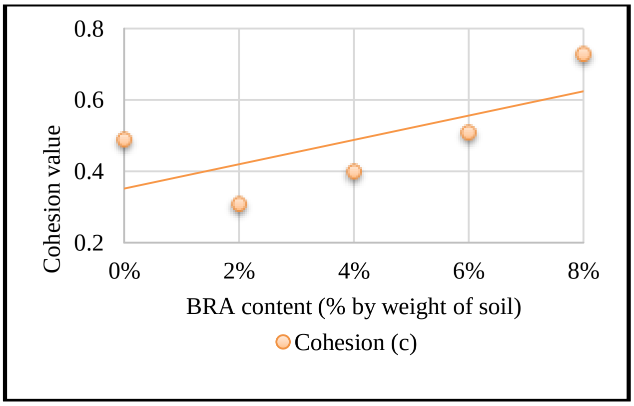

Figure 5 Cohesion values of soil-BRA mixture

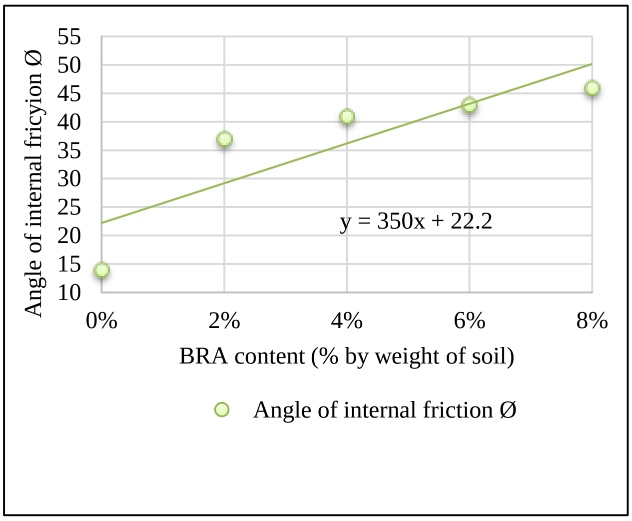

Figure 6 Angle of internal of soil-BRA mixture

5.2 Soil-Sand Stabilization

5.2.1 Atterberg Limit

Similar to the soil-BRA, Plasticity Index (PI) decreased with increase in sand content of the soil. The Atterberg test results of soil-sand are given in Table 5 and Fig. 7 also shows that the PI value is low if the percentage of sand content increases. These results correspond to the directional hypothesis that lowering of PI value, decreases the potential of soil to become expansive. This means that by adding more sand, the soil will become less expansive. Decrease in PI value was caused by reduction in pores of the soil that was filled by sand.

Table 5 Plasticity Index (PI) of soil-sand

% of BRA	LL	PL	PI
0%	76	42	34
5%	72	46.3	25.7
10%	71	33.31	37.9
15%	60	31.79	28.21
20%	59	29.15	29.85
25%	52	28.18	23.82

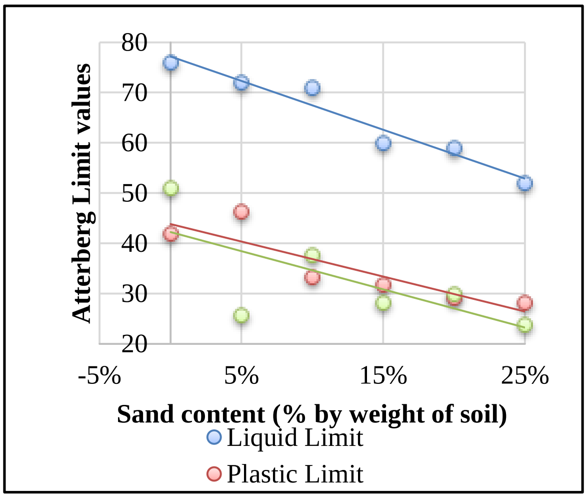

Figure 7 Atterberg limit values of soil-sand

5.2.2 California Bearing Ratio (CBR) Test

The result of CBR test for sand stabilize expansive soil is shown in Fig. 8. The result shows that increase in sand content results in higher value of CBR. Regression model give the coefficient of determination, R^2 = 0.9638 and coefficient of correlation R = 0.9823 which indicates strong correlation between the CBR value and sand content.

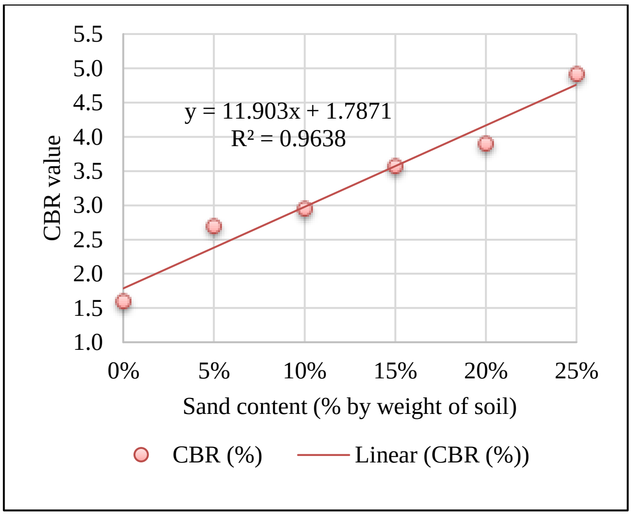

Figure 8 CBR values of soil-sand mixture

5.2.3 Direct Shear Test

The results of direct shear test for sand stabilized soil are shown in Fig. 9 and 10 for cohesion value and angle of internal friction Ø respectively. The results show the normal value of Ø, where the higher cohesion value, the lower the angle internal friction Ø. Cohesion value of natural soil (0% of sand) was 0.49 kg/cm^2 and angle of internal friction Ø was 14°. The percentage increase in sand content results in higher angle of internal friction and lower cohesion.

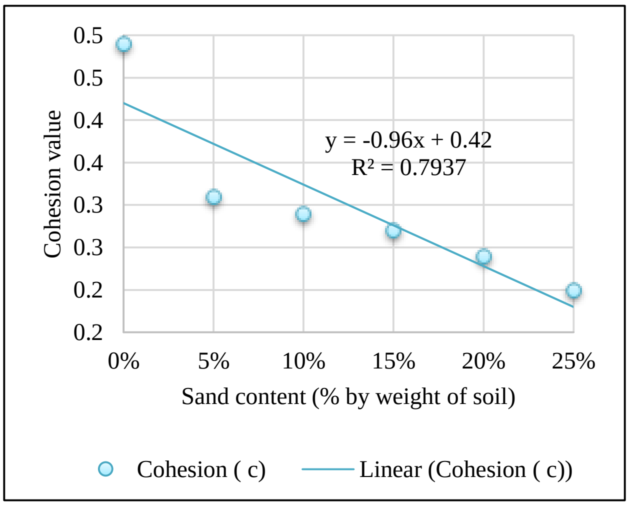

Figure 9 Cohesion values of soil-sand mixture

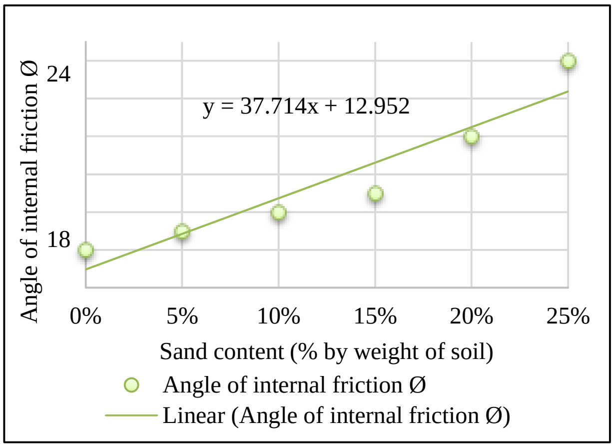

Figure 10 Angle of internal friction of soil-sand mixture

5.2.4 Discussion On Direct Shear Test Results

By adding 8% BRA, the value of cohession of soil-BRA is 0.624 and the value of angle of internal friction Ø was 50.2º. While with the same presentage, the cohesion value of soil-sand is 0.34 and angle of internal friction Ø is only 16º. In addition, the BRA contains rock particles which makes BRA-soil mixture to be clotted, hard, and granular which results in high value of angle of internal friction.

■6.0 CONCLUSIONS

From the results of BRA and sand stabilizer, it was found that with only 8% of BRA content, the soil becomes significantly less expansive and by adding sand with BRA increases the angle of internal friction Ø and reduces the cohesiveness of the [10] soil. Therefore, it can be concluded that BRA can be used and suitable to stabilize expansive clay soil

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