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Engineering Behaviour of Clay Shale Stabilized with Asphalt Emulsion and Artificial Lightweight Aggregate Perlite

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ABSTRACT
Soil plays a vital role in the planning stage of road construction. The subgrade, representing the final construction that receives the vehicle load transmitted by the pavement, is of critical importance. Clay shale is among the most challenging soil types due to its susceptibility to weathering when exposed to water or air. In the wake of geotechnical challenges precipitated by clay shale soil, there arises a pressing need for soil stabilization initiatives aimed at enhancing the soil's physical properties. The present study utilizes two stabilization materials: asphalt emulsion and artificial light weight aggregate perlite. The initial soil physical properties and mechanical properties (Unconfined Compressive Strength Test) were obtained through laboratory testing. Preliminary findings from rigorous testing and in-depth analysis have yielded notable results. The highest ultimate unconfined compressive strength value, as determined by a 14-day curing period with an asphalt content of 8% and an artificial light weight aggregate of 1%, has been recorded at 2,301 kg/cm2.
Keywords: *Clay Shale, Soil Stabilization, Asphalt Emulsion, Artificial Light Weight Aggregate Perlite*

INTRODUCTION

Infrastructure development in Indonesia has been observed to increase annually, encompassing the construction of high-rise buildings, residential housing, roads, and dams, among other infrastructure. Geotechnical science, the scientific study of the physical and mechanical properties of soil and rock, plays a vital role in infrastructure planning due to its influence on the stability, strength, and durability of constructed infrastructure (Adisurya et al., 2022).

Clay shale is a problematic soil type that has been implicated in numerous construction failures throughout Indonesia. This phenomenon can be attributed to the inherent characteristics of clay shale soil, which is susceptible to weathering when exposed to the elements or moisture (Pratama, 2021). The term "clay shale" refers to a particular type of sedimentary rock characterized by the presence of elongated faults, which manifest as thin laminae or layered layers with a thickness of less than 1 centimeter. These elongated faults are known as "fissilities" (Alatas, 2020). The instability of clay shale can occur even on flat contours, which has been shown to cause significant problems in the field of geotechnical infrastructure planning (Yusuf et al., 2017). The instability of clay shale soil has led to complications in the construction of the Sigli Banda Aceh toll road STA 10 + 800, specifically in the cut and fill operations. This has resulted in landslides, which have further compounded the challenges posed by the subgrade's dual-seasonal behaviour. In dry periods, the subgrade hardens to a consistency comparable to rock, while during the rainy season, it undergoes a transition to a soft state (Sabrina et al., 2023).

In the instance of geotechnical problems caused by clay shale soils, efforts must be made to stabilize the soil. Soil stabilization is a soil engineering method that aims to improve and maintain certain properties of soil in order to meet the required technical requirements (Darwis, 2018). In the domain of geotechnics, a range of soil stabilization techniques have been examined by researchers. These include the use of fly ash, cement, lime, plastic waste, and a variety of other mixed materials (Gbenga Matthew & Shola Paul, 2018). This study utilizes asphalt emulsion additives and Artificial Light Weight Aggregate (ALWA) as a mixture in clay shale soil to ascertain alterations in the physical and mechanical properties of soil.

Artificial light weight aggregate is an artificial light weight aggregate made by heating materials such as tar, iron smelting, clay, diatome, fly ash, shale soil and clay (Darayani, 2018). Artificial light weight aggregate can also be made from vermiculite and perlite which are volcanic rocks that can expand when heated slowly or quickly. Approximately 6700 million tons of perlite are estimated to exist globally. While perlite exhibits pozzolanic properties, its application in soil stabilization remains unexplored (Calik & Sadoglu, 2014). Artificial light weight aggregate from perlite has good water absorption ability as a soil stabilization material. While asphalt emulsion stabilization material is defined as a process when a certain amount of asphalt is mixed with soft soil to form a stable soil condition as required as a subgrade. Stabilization materials in the form of asphalt will increase the resistance to water (Wicaksono et al., 2023). The water in the emulsion mixes easily with the soil, and cured asphalt increases the material's strength. Also to its credit is the ability of soil stabilized with asphalt emulsion deformation by the forces of traffic and water (Oluyemi-Ayibiowu, 2019). Good asphalt emulsion levels for stabilization with soil are between 6% to 8% depending on the plasticity of the soil (Tarigan & Syahril, 2021). the addition of asphalt emulsion could significantly improve the mechanical properties of lateritic soils, such as unconfined compressive strength (UCS) and California Bearing Ratio (CBR) (de Medeiros et al., 2024). This research was carried out testing the unconfined compressive strength of the soil, to determine the strength value with cylindrical samples from the compaction results (Irawati & prihatiningsih, 2018). The free compressive strength test is a commonly conducted test used in the process of investigating soil stabilization properties. The axial pressure applied above the specimen is gradually increased until the specimen collapses (Amran & Yuda Pradana, 2023).

METHOD

Research Location

The present study utilized clay shale soil obtained from the Serang-Panimbang Banten toll road project. The asphalt emulsion stabilization materials were obtained from PT Perkasa Adiguna Sembada, and the artificial light weight materials were obtained from PT Dumas Tolinsultek Sunijaya. The soil investigation will be conducted at the Geotechnical Laboratory, which is affiliated with the Civil Engineering Department at the Polytechnic of Bandung State.

Data

The present study utilizes both primary data obtained through laboratory test results and secondary data concerning the content of added materials. In this study, experiments were conducted on native soil and on various combinations of mixtures, with a consistent 8% proportion of asphalt emulsion each mixture and varying levels of artificial light weight aggregate (1%, 2%, 3%, and 4%). The duration of the curing process is subject to variation, with options ranging between 0 days, 3 days, 7 days, and 14 days.

The subsequent section will present the outcomes of a thorough chemical analysis. The focus of the analysis was an artificially lightened aggregate perlite material. The mineral composition of artificial light weight aggregate perlite can be seen in **Table 1**.

Table 1. Mineral Composition of Artificial Light Weight Aggregate Perlite

Mineral composition	Percentage (%)
Silicon dioxide: SiO_2	70-75
Aluminium oxide: AI_2O_3	12-15
Sodium oxide: Na_2O	3-4
Potassium oxide: K_2O	3-5
Iron oxide: Fe_2O_3	0,5-2
Magnesium oxide: MgO	0,2-0,7
Calcium oxide: CaO	0,5-1,5
Loss on ignition (chemical/combined water)	3-5

Analysis Method

The present study utilized four distinct samples to ascertain the impact of incorporated materials and four variations in the curing period. The preparation of test samples for the UCS test entailed a series of meticulous procedures, including mixing, curing, and compaction (Faray & Rahayu, 2020). Compaction was performed using modified type compaction. The compaction parameters obtained from this test are very important in the soil improvement process and are used to meet the relative compaction requirements listed in the project specifications (Khalid & Rehman, 2018). Variation of stabilization material content and clay shale soil in each specimen, can be seen in **Table 2**.

Table 2. Proportion of Weight of the Sample Soil and the Stabilisation Material

Soil Type	Weight of Soil	Weight of Asphalt Emulsion (AE)	Weight of Artificial Light Weight Aggregate (ALWA)	Total Weight
	(gram)			
Clay Shale	4000	0	0	4000
Variation 1 (8% AE + 1% ALWA)	4280	320	40	4000
Variation 2 (8% AE + 2% ALWA)	4240	320	80	4000
Variation 3 (8% AE + 3% ALWA)	4200	320	120	4000
Variation 4 (8% AE + 4% ALWA)	4160	320	160	4000

The total number of samples made in this study was 51 samples which were then varied based on the curing time, can be seen in **Table 3**.

Table 3. Number of UCS Test Samples

number of samples	Curing Time (day)			
	0	3	7	14
Clay Shale	3	-	-	-
Variation 1 (8% AE + 1% ALWA)	3	3	3	3
Variation 2 (8% AE + 2% ALWA)	3	3	3	3
Variation 3 (8% AE + 3% ALWA)	3	3	3	3
Variation 4 (8% AE + 4% ALWA)	3	3	3	3

The flowchart illustrating the research process is presented in **Figure 1**.

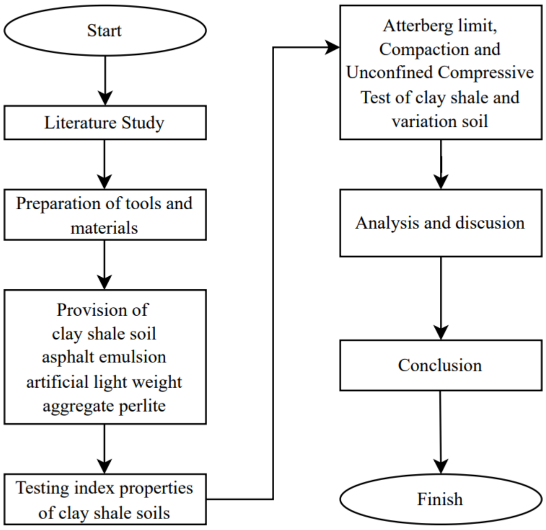

Figure 1. Research Flowchart

The testing standards used as guidelines for conducting research are as follows, can be seen in **Table 4**.

Table 4. Testing Standards in This Research

Testing	Testing Standards
Specific Gravity	(ASTM D-854-02, 2002)
Atterberg Limit	(ASTM D4318-17, 2017)
Water Content	(ASTM D2216-98, 2019)
Weight of Content	(ASTM D2216-98, 2019)
Dry Weight	(ASTM D2216-98, 2019)
Pore Value	(ASTM D2435, 2011)
Porosity	(ASTM D2435, 2011)
Compaction	(ASTM D1557-12, 2012)
Unconfined Compressive Strength	(ASTM D2166-06, 2006)

RESULT AND DISCUSSION

The Following Report Presents the Results of a Clay Shale Soil Index Properties Test.

The test results of the index properties of clay shale soil, in the form of testing the specific gravity, Atterberg limit, content weight, pore value, water content, dry weight, and porosity of the soil, can be seen in **Table 5**.

Table 5. Property Index of Clay Shale Soil

Number	Testing	Symbol	Unit	Value
1	Specific Gravity	Gs	-	2.686
2	Atterberg Limit			
	Liquid Limit	LL	%	53.86
	Plastic Limit	PL	%	32.65
	Plasticity Index	PI	%	21.21
3	Weight of content	γ	gr/cm^3	1.70
4	Pore value	e	-	1.34
5	Water content	ω	gr/cm^3	48.88
6	Dry weight	γd	gr/cm^3	1.14
7	Porosity	n	-	0.57

Atterberg Limit Test Results of Mixed Soil

The summary of Atterberg limit test result can be seen in **Table 6**, and the Atterberg limit graphic can be seen in **Figure 2**.

Table 6. Summary of Atterberg Limit Test Results

Testing	Symbol	Value (%)				
		Clay Shale	Variation 1	Variation 2	Variation 3	Variation 4
Liquid Limit	LL	53,52	38,14	38,75	39,91	41,13
Plastic Limit	PL	21,21	29,63	30,00	30,90	31,76
Plasticity Index	PI	32,31	8,51	8,75	9,01	9,38

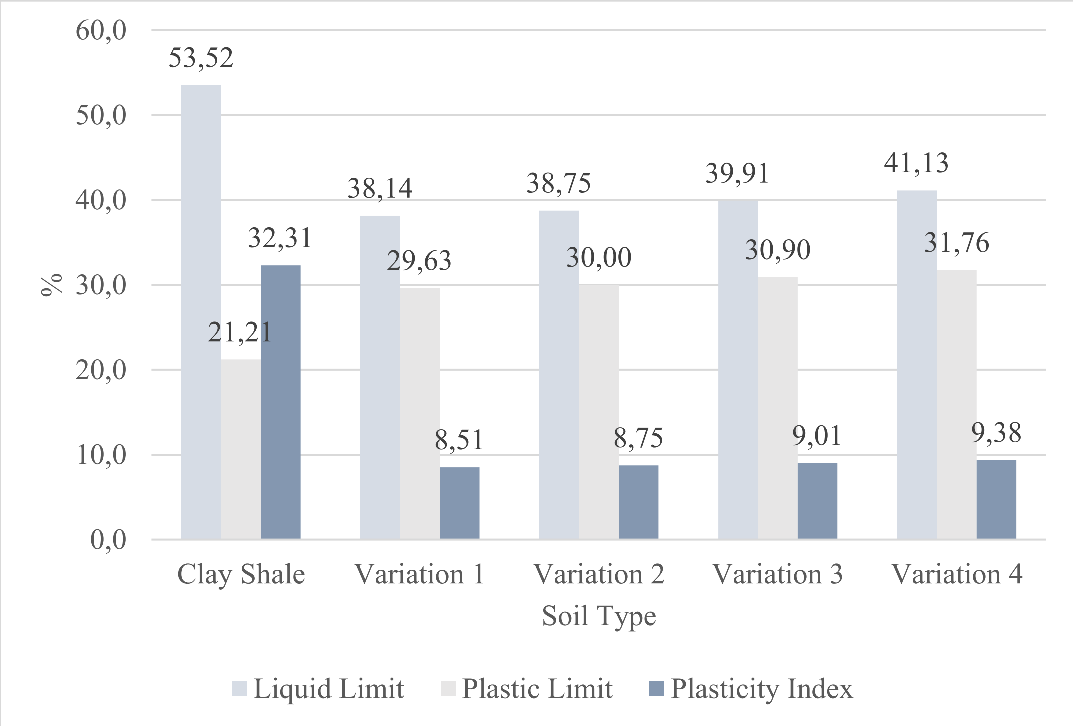

Figure 2. Atterberg Limit Testing Graphic

Based on the test results, the addition of ALWA stabilization material and asphalt emulsion to clay shale soil caused a decrease in the liquid limit value and plasticity index, while the plastic limit value increased. The decrease in the maximum liquid limit value occurred in mixture variation 1 by 31.05% from the previous 53.52% to 38.14%. The decrease in the maximum plasticity index value occurred in mix variation 1 by 279.67% from the previous 32.31% to 8.51%. The decrease in liquid limit value and plasticity index indicates that the soil becomes more stable, less plastic, and more resistant to the influence of water content.

Soil Compaction Test Results of Variation Soil

In the domain of soil stabilization, soil compaction testing constitutes a crucial step in ensuring the optimal density and stability of the soil to support construction activities. This testing involves determining the maximum moisture content and dry weight of the soil, thereby facilitating the determination of its suitability for construction purposes. The outcomes of the soil compaction testing are displayed in **Table 7** and the soil compaction graphic can be seen in **Figure 3**.

Table 7. Soil Compaction Test Results

Testing	Unit	Clay Shale	Variation 1	Variation 2	Variation 3	Variation 4
Optimum Moisture Content (w_{opt})	%	28,80	26,83	27,79	27,97	28,33
Maximum Dry Density (γ_{dmax})	gr/cm^3	1,34	1,41	1,39	1,37	1,35

Based on the results of soil compaction testing, the optimum moisture content of clay shale soil decreased. However, an increase in ALWA stabilization material caused an increase in the optimum moisture content. The maximum decrease in optimum moisture content occurred in variation 1; the previous moisture content of 28.80% decreased to 26.83%. Soil compaction testing also showed an increase in maximum dry weight, from 1.34 g/cm³ to 1.41 g/cm³, in variation 1. However, the addition of ALWA levels decreased the maximum dry weight. An increase in maximum dry weight indicates denser soil particles, which can increase the soil's capacity to withstand structural loads.

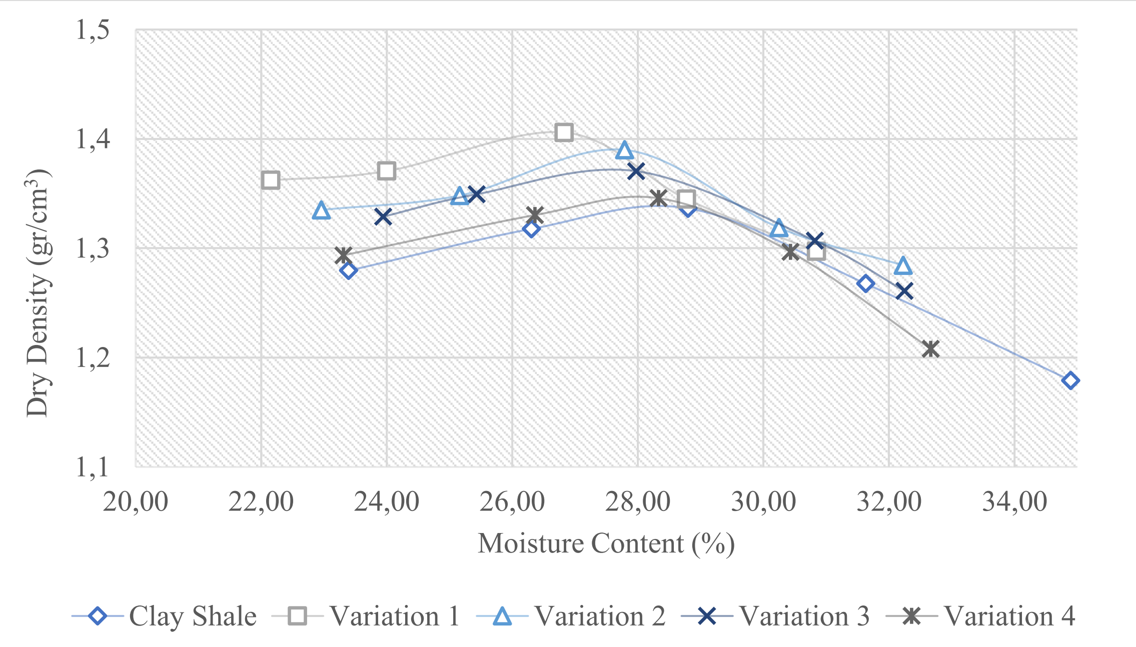

Figure 3. Soil Compaction Graphic

Unconfined Compressive Test Result of Variation Soil

The summary of UCS testing result can be seen **Table 8** and the effect of curing time on UCS test can be seen in **Figure 4**.

Table 8. Summary of UCS Testing Results

Number	Soil Type	Unit	Curing Time			
			0 day	3 days	7 days	14 days
			q_u			
1	Clay Shale	kg/cm²	0,402	-	-	-
2	Variation 1	kg/cm²	1,650	1,741	1,976	2,301
3	Variation 2	kg/cm²	1,387	1,638	1,685	1,836
4	Variation 3	kg/cm²	1,345	1,568	1,614	1,718
5	Variation 4	kg/cm²	1,080	1,125	1,174	1,431

Based on the UCS test results, there was an increase in the unconfined compressive strength (q_u) value of the stabilized soil, but as the artificial light weight aggregate content increased, it decreased again. The maximum increase in unconfined compressive strength (q_u) value occurs in mixture variation 1 with an increase in the previous unconfined compressive strength value of 0,402 kg/cm^2 to 2,301 kg/cm^2. The maximum percentage increase that occurred was 472% with the maximum increase occurring in the 14-day holding period.

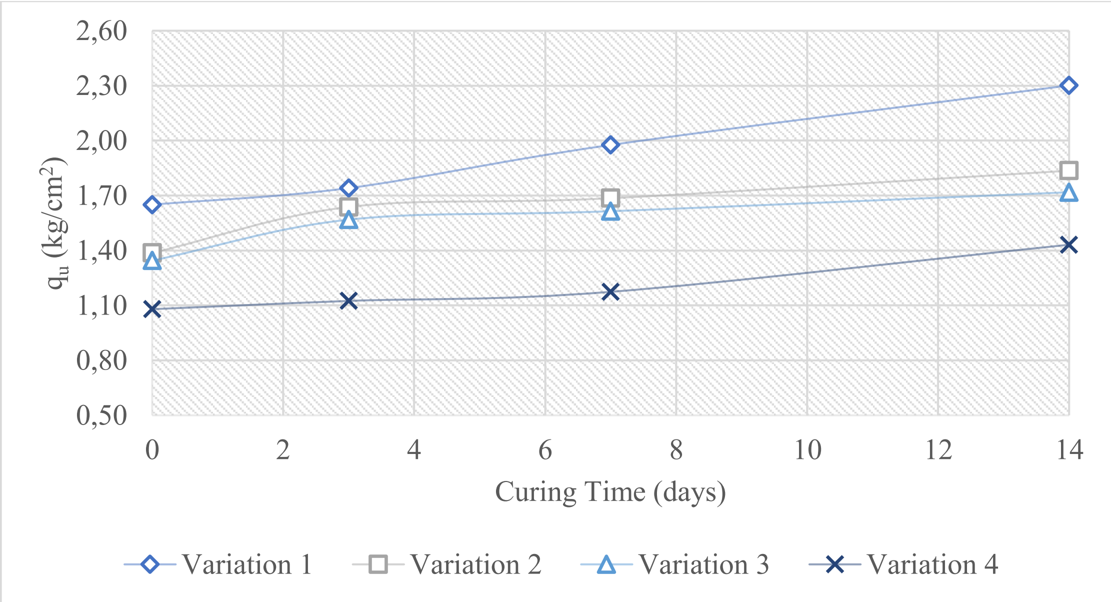

Figure 4. The Effect of Curing Time on UCS Test

CONCLUSIONS

The findings indicated that the stabilization of clay shale soil through the application of a blend of Artificial Lightweight Aggregate (ALWA) and asphalt emulsion exerted a favorable influence on the soil's plasticity index and mechanical strength.

The incorporation of stabilization materials resulted in a decline in liquid limit value and plasticity index, accompanied by an increase in plastic limit value. This observation indicates an enhancement in soil stability in response to variations in moisture content. The maximum recorded decrease in the liquid limit value was 31,05%, observed in variation 1, while the most substantial decline in plasticity index was 279,67%, noted in variation 1. This phenomenon suggests that the stabilized soil becomes less plastic and more volumetrically stable.

From a mechanical perspective, the compaction process leads to a decrease in the optimum moisture content, which is maximum in variation 1. This decrease is evident when the initial moisture content of 28,80% is reduced to 26,83%. Concurrently, there is an observed increase in the maximum dry weight from 1,34 g/cm^3 to 1,41 g/cm^3. the unconfined compressive strength (UCS) test results demonstrated a substantial enhancement in soil strength following the stabilization process. The maximum increase in unconfined compressive strength value occurred in variation 1, with an increase from 0,402 kg/cm^2 to 2,301 kg/cm^2 after a 14-day curing period, equivalent to an increase of 472%. However, an excessive increase in ALWA content has been observed to result in a subsequent decrease in the unconfined compressive strength value.

The combined use of ALWA and emulsified asphalt was found to be effective in enhancing the performance of clay shale soils with regard to plasticity and mechanical strength. The optimum proportion of materials was identified as a pivotal factor in achieving success.

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