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The Effect of Palm Kernel Shell Ash and Calcium Sulfate Dihydrate on the Properties of Clay Soil for Road Repair

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ABSTRACT

The subgrade around Dusun Paloh 80, Desa Tanjung Rejo, Percut Sei Tuan, Deli Serdang Regency, is a clay-type soil with fine grains and low stability. Therefore, a soil stabilization method must be used to achieve a more stable soil. The purpose of this study was to determine the value of clay soil swelling and the effect of adding palm shell ash and calcium sulfate dihydrate at percentages of 0%, 4%, 6%, 8%, 10% and 12% on the plasticity index and shrinkage limit. Soil stabilization is the mixing of soil with certain materials to improve its technical properties and meet specific requirements. In this study, clay soil stabilization was achieved using palm shell ash and gypsum. Tests were conducted based on the ASTM method. The largest swelling occurred at 12% in a 14-day soaking at 13.08%, and the smallest at 12% in a 1-day soaking at 0.57%. The correlation between the plasticity index and the swelling limit is that the greater the plasticity index, the greater the swelling; meanwhile, the greater the shrinkage limit, the smaller the swelling.

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1. INTRODUCTION

Clay soil exhibits plastic properties when mixed with water. The properties consist of microscopic and submicroscopic particles, invisible to ordinary microscopes, in the form of flakes such as mica, clay minerals, and very fine minerals [1]. Clay soil has low bearing capacity, which often poses an obstacle to construction, especially in road construction [2]. The soil's natural properties are highly sensitive to water content values, leading to significant volume changes [3]. The subgrade layer often loses stability, leading to damage such as cracks, waves, and subsidence of the road surface [4]. To overcome these problems, a soil improvement approach

is needed that not only increases soil strength but also complies with the principles of efficiency and economy [5].

Efforts to improve the quality of clay soil are generally carried out through stabilization techniques that use additives to enhance the soil's physical and mechanical properties. In road pavement construction, soil stabilization is the improvement of existing local road materials, either by mechanical stabilization or by adding an additive [6]. In road pavement design, each pavement layer must meet specific requirements. Each component of the pavement layer must be able to withstand shear, excessive deflection that causes cracking of the underlying soil layer, and prevent excessive permanent deformation

due to compaction of the constituent material [7]. Stabilizing soil material improves its quality. Clay soil is characterized by its hardness when dry but becomes soft, plastic, and cohesive when wet, expanding and contracting rapidly, resulting in significant volume changes [8]. Clay consists of very small grains and possesses cohesion and plasticity, properties not found in sand and gravel [9]. Cohesion means that the grains stick together, while plasticity is a property that allows the soil to change shape without changing volume and without causing cracks or breaks [10]. In various regions, there is a type of soil called expansive or swelling clay, which expands when water from its surroundings infiltrates it, damaging nearby buildings and other structures. Expansive soil is characterized by significant shrinkage and expansion, expanding during the rainy season and shrinking during the dry season [11].

Swelling soils are typically found in flat areas, where water seepage results in weathering that forms clay minerals such as montmorillonite. These minerals typically undergo rapid volume changes due to changes in water content [5]. The development mechanism is as follows. In hot, dry climates, clay is usually in a compressed state due to negative pore-water pressure. When it comes into contact with water, for example, from rain, clay absorbs water and expands [12]. This increase in water content means that the pore water pressure decreases so that the effective stress increases, accompanied by a change (increase) in volume [13].

In essence, the behavior of low-seepage clays is the opposite of that of coarse-grained clays. Because of their low seepage coefficients, their seasonal effects are not deep and may not reach the water table. During dry weather, water is lost through evaporation at the surface, causing pore water pressure to become more negative and water flows toward the surface. The soil shrinks, and areas near the surface become unsaturated. During wet weather, the pore water pressure at the surface becomes zero, and water infiltrates the soil and seeps downward. The soil gradually absorbs the water and expands [14].

The potential for expansion is the ability of the soil to expand, expressed as a percentage, with the formula:

$$S_w = x \ 100 \ (1) \frac{\Delta H}{h_0}$$

Where:

ΔH = Comparison of soil sample height (cm)

h_0 = Initial height of soil sample (cm)

Table 1. Classification of Expansive Swelling Degree

Swelling Potential (%)	Swelling Degree
0 – 1.5	Low
1.5 – 5	Medium
5 – 25	High
> 25	Very High

The consistency of clay and other cohesive materials is strongly influenced by soil water content, plasticity index, and swelling limit. Swelling characteristics can be estimated only from the plasticity index. The higher the plasticity index, the greater the swelling percentage. Laboratory swelling is a simplified method for observing factors that influence the process occurring in the field [15].

Table 2. Classification of the Degree of Expansiveness of Plasticity Index Against Swelling

Plasticity Index (%)	Swelling Potential
0 – 15	Low
10 – 35	Medium
20 - 35	High
> 35	Very High

Soil swelling and shrinking are largely the result of capillary action or changes in water content. Soils high in clay experience volume changes when their water content changes. A decrease in water content, followed by an increase in effective stress, causes the soil volume to shrink, while an increase in water content causes expansion [16]. The shrinkage limit (SL) is defined as the water content at the boundary between the semi-solid and solid regions. It is the percentage of water content at which subsequent changes in soil volume do not alter it. The higher the shrinkage limit, the smaller the percentage of expansion. The higher the shrinkage limit, the more difficult it is for the soil to undergo volume changes. The higher the shrinkage limit, the more water is required to achieve a volume change [17].

Table 3. Classification of Expansive Soil Based on Shrinkage Limit

Linear Shrinkage	SL (%)	Probable Swell (%)	Degree of Expansion
<5	>12	<0.5	Non-Critical
5 – 8	10 -12	0.5 – 1.5	Marginal
>0.8	<10	<1.5	Critical

Stabilization in this study uses more economical alternative materials, specifically solid waste from industrial and agricultural activities, which remain abundant in Indonesia. One waste with significant potential for utilization is palm shell ash (PSA), a byproduct of burning palm shells and fiber in palm oil processing plants. This material is rich in silica (SiO₂) and alumina (Al₂O₃), which function as natural pozzolanic materials, reacting with calcium compounds to form bonds that strengthen soil structure [5]. In addition, adding calcium sulfate dihydrate (CaSO₄·2H₂O) or gypsum can increase bond strength between soil particles and reduce plasticity, making the soil denser and more stable [18]. The combination of these two materials is expected to create a synergistic effect that can significantly improve the characteristics of clay soil.

A variety of stabilizing agents have been used in road construction. These agents, or additives, for cementation can include cement, lime, lime-fly ash mixtures, asphalt, and others. These materials act as binders, permanently binding soil particles or aggregates, resulting in larger-grained soil [19]. These larger grains reduce the plasticity of the original soil before mixing and increase its strength. Stabilizing agents are selected based on soil type, site conditions, and the economics of their use. Therefore, in stabilization with admixtures, the soil on site remains intact, with no excavation or replacement required. The amount of admixture is generally determined by laboratory tests that simulate field conditions, weather, durability, or strength testing. Several factors should be considered when selecting the appropriate admixture type, as shown in Table 4.

Table 4. Suitable soil stabilization applications

Soil Type	Fine Clay	Coarse Clay	Fine Silt	Coarse Silt	Fine Sand	Coarse Sand
Grain Size (mm)	<0.006	0.006-0.002	0.01-0.06	0.01-0.06	0.2-0.4	0.4-2.0
Soil Volume Stability	Very Poor	Moderate	Good	Very Good	Good	Very Good
Stabilization Type	Lime					
	Cement					
	Asphalt					
	Polymeric-Organic					
	Mechanical					
	Thermal					

Palm kernel shell ash is the residue from burning the shells and fibers of oil palm fruit in the furnace or kiln of a palm oil processing plant. This research will explore alternative soil stabilization materials using unused palm oil waste, specifically palm kernel shell ash. The availability of palm kernel shell ash enables its use as a construction material. In principle, palm kernel shell stabilization involves directly mixing the palm kernel shell ash with crushed soil, adding water, and then compacting. The resulting mixture is expected to produce soil with improved technical

properties or characteristics compared to the original soil [4].

Table 5. Composition of Palm Kernel Shell Ash

Elements / Compounds	Palm kernel shell ash (%)
Silica (SiO ₂)	65.3
Aluminum Carbonate (Al ₂ O ₃)	11.3
Iron Oxide (Fe ₂ O ₃)	1.12
Calcium Oxide (CaO)	6.48
Magnesium Oxide (MgO)	4.28

Palm shell ash was used in this study as a stabilizing material for a clay-based soil mixture in the road layer. The addition of palm shell ash aims to enhance the stability and strength of the clay, which typically has high plasticity and is prone to changes in moisture content. By incorporating palm shell ash, it is expected to reduce the excess moisture in the clay and improve its resistance to traffic loads. This use of a natural material not only offers a cost-effective alternative for road construction but also presents an environmentally friendly solution, as palm shells, which are often discarded, can be repurposed into a valuable material.

The use of calcium sulfate dihydrate as an alternative additive to stabilize clay soil is expected to improve soil quality, as the mineral's chemical composition includes silica (SiO₂) and lime (CaCO₃), both commonly used in soil stabilization. Calcium sulfate dihydrate is one example of a mineral with a dominant calcium content.

In chemistry, calcium sulfate dihydrate is referred to as (CaSO₄·2H₂O), and is included in the sulfate minerals, which have very profitable value, so they are widely available and easy to obtain in nature [20]. The advantages of calcium sulfate dihydrate in Civil Engineering work are. Calcium sulfate dihydrate has a very high calcium content, so when mixed with clay soil, it can reduce the occurrence of cracks because its expansion is smaller. Calcium sulfate dihydrate contains calcium, which binds soil organic matter in clay soils, thereby increasing the stability of soil aggregates. Calcium sulfate dihydrate absorbs large amounts of water, which can increase the rate of water seepage. Calcium sulfate dihydrate, as a mineral adhesive, has better properties than organic adhesives because it does not cause air pollution, is inexpensive, is fire-resistant, is resistant to biological deterioration, and is resistant to chemicals.

This study aims to analyze the effect of a mixture of palm kernel shell ash and calcium sulfate dihydrate on the physical and mechanical properties of clay soil, particularly when used as a base layer for road pavements. Using a laboratory approach, this research is expected to contribute to the scientific development of local waste-based soil stabilization technology in civil engineering.

2. METHODOLOGY

This research was divided into several testing stages: testing the soil's physical properties, testing its mechanical properties, and reviewing its development (swelling). The testing steps and laboratory examinations were carried out based on standard methods according to ASTM (American Society for Testing and Materials), with the addition of palm shell ash waste and calcium sulfate dihydrate variables of 0%, 4%, 6%, 8%, 10% and 12% of the soil weight. Then, checks were carried out starting from 1, 4, 7, and 14 days.

Table 6. ASTM Research Standards

PHYSICAL PROPERTIES OF SOIL		
No.	Item	Standard
1	Water content	ASTMD2216 – 98
2	Consistency Limit (Atterberg Limit):	ASTM D 4318 – 83
	a. Liquid Limit	ASTM D 423 – 66
	b. Plastic Limit	ASTM D 424 – 74
	c. Shrinkage Limit	ASTM D 424 – 72
3	Specific Gravity	ASTM D 854 – 72
4	Sieve Analysis	ASTMC 136 – 46
5	Hydrometer Test	ASTM D 442 - 98
MECHANICAL PROPERTIES OF SOIL		
1	Soil Compaction Test	ASTMD 698 – 12
REVIEWED TESTS		
1	Land Development (Swelling)	ASTM D 4546 – 14

In his research on soil stabilization, namely the use of palm shell ash, a by-product of Palm Oil Processing Factories. PT. Multi Agrindo Sumatera, Jalan Besar Lubuk Pakam – Dolok Masihul Km. 55, Karang Tengah Village, Serba Jadi District, Serdang Bedagai Regency. The tests conducted were the consistency limits of clay soil before and after being mixed with palm shell ash. Compaction testing of native soil and stabilized soil, as well as swelling testing of native soil and stabilized soil with palm shell ash. The results showed that adding palm shell ash to clay soil

reduced pressure and swelling potential, but the effects were not significant. Then, the stabilization of this base soil was added by using calcium sulfate dihydrate. Tests were carried out with percentages of 0%, 4%, 6%, 8% and 12%. At percentages between 0% and 12%, there was an increase, but at 12% there was a decrease.

In this study, calcium sulfate dihydrate will be added to stabilize soil using unused palm oil waste in the form of palm kernel shell ash. The availability of palm kernel shell ash and calcium sulfate dihydrate enables their use for clay soil stabilization. In principle, the purpose of stabilizing palm kernel shell ash and calcium sulfate dihydrate is to mix them directly with crushed soil, then add water and compact it. The resulting mixture is expected to produce soil with better technical properties or characteristics than the original soil.

3. RESULTS AND DISCUSSION

Based on the results of research conducted at the Soil Mechanics Laboratory of Medan State Polytechnic, the physical properties of original clay soil were obtained with values as shown in Table 7 below.

Table 7. Results of Testing the Physical Properties of Soil and a Mixture of Palm Kernel Shell Ash & Calcium Sulfate Dihydrate

Soil Properties	Unit	Clay Soil					
		0%	4%	6%	8%	10%	12%
		PSA + CSH					
Specific Gravity (GS)		2.60	2.52	2.48	2.41	2.30	2.26
Liquid Limit (LL)	%	50.13	49.76	49.76	49.69	47.89	46.51
Plastic Limit (PL)	%	29.89	31.33	32.38	33.32	30.62	33.48
Plasticity Index (PI)	%	20.24	18.44	17.38	16.36	16.27	13.03
Shrinkage Limit (SL)	%	39.06	40.62	43.74	45.57	50.42	56.17
Sieve Analysis	%	94.64	94.64	94.58	94.56	94.32	94.08
Dry Bulk Weight	gr/cm3	1.33	1.39	1.39	1.41	1.42	1.43

The specific gravity of clay soil taken from the research location from Table 7 shows that the soil is classified as organic clay soil because its value is between (2.58 – 2.65) gr/cm³.

Based on the test results, the liquid limit (LL) of the original soil is 50.13%. Meanwhile, the results of the

plastic limit (PL) test on the original soil are 29.89%, and the plasticity index (PI) value is 20.24%. It can be concluded that the land Desa Percut Sei Tuan, Deli Serdang Regency, is classified as clay soil with a fairly high PI (Plastic index) of 20.24%. The specific gravity of clay soil taken from the research location, then from Table 4.1, shows that the soil is classified as organic clay soil because the value is between (2.58 – 2.65) gr/cm³. According to AASTHO (American Association of State Highway and Transportation Officials), the liquid limit was 50.13% and the plastic index was 29.89%, indicating that the soil falls within the A-7-6 group.

3.1. Swelling Results

The swelling value in mixed soil is lower as the mixture content increases. The limit of the cementation process between clay granules, palm shell ash, calcium sulfate dihydrate, and water is at 14 days of curing. The smallest swelling value is found with the addition of 12% palm shell ash and calcium sulfate dihydrate, namely 0.57% after 1 day of soaking. Moreover, the largest swelling value is found in clay soil without a mixture of palm shell ash and calcium sulfate dihydrate, namely 13.08% after 14 days of soaking. As seen in Figure 1 below:

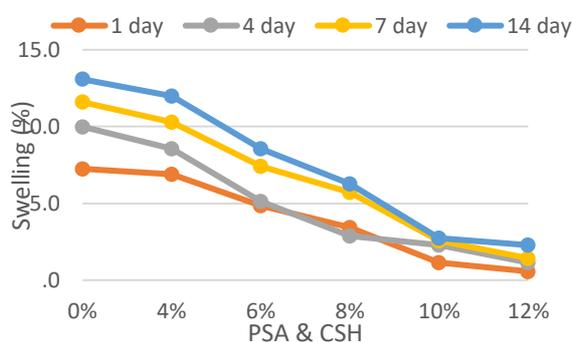


Fig.1 Development of Soaking with Various Mixtures of Palm Shell Ash & calcium sulfate dihydrate

Based on the graph above, the swelling value of clay stabilized with palm shell ash and calcium sulfate dihydrate decreases with increasing percentages of both additives. However, it increases with increasing immersion time. This value is due to the rapid volume change caused by changes in water content. This increase in water content means pore water pressure decreases, increasing effective stress and a change (increase) in volume. The pore water pressure at the surface becomes zero, and water will enter the soil and seep downward. The soil will slowly absorb water and expand.

3.2. Relationship of Plasticity Index to Development

From the results of the plasticity index test on swelling with immersion time of 1, 4, 7, and 14 days with a mixture composition of 0%, 4%, 6%, 8%, 10%, and 12% palm kernel shell ash and calcium sulfate dihydrate, can be seen in Table 9 and Figure 2. From the test results, the largest plasticity index is obtained with 0% palm kernel shell ash and calcium sulfate dihydrate, namely 20.24%, and decreases to 12%, namely 13.03%. The swelling value also decreases as the percentage of the palm kernel shell ash-calcium sulfate dihydrate mixture increases. The largest swelling value is 13.08% at 0% immersion time for 14 days, and the smallest is 0.57% at 12% immersion time for 1 day.

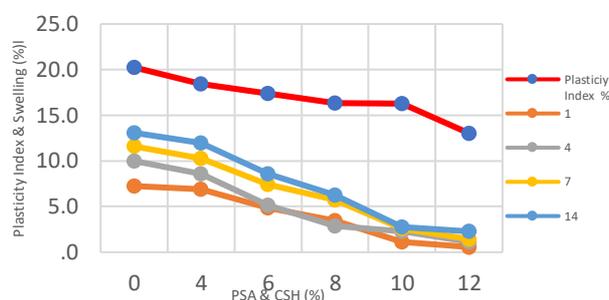


Fig. 2 Graph of the Relationship between Plasticity Index and Swelling with the Percentage of Palm Kernel Shell Ash and Calcium Sulfate Dihydrate Mixture

Based on the graph above, the Plasticity Index (PI) value for clay stabilized with palm shell ash and calcium sulfate dihydrate decreases as the percentage of palm shell ash and calcium sulfate dihydrate increases. This results in a decrease in the clay's potential swelling value. The higher the plasticity index, the greater the percentage of swelling.

3.3. Relationship between Shrinkage and Expansion Limits

From the results of the shrinkage limit test against swelling with a soaking time of 1, 4, 7, and 14 days with a mixture composition of 0%, 4%, 6%, 8%, 10%, and 12% palm shell ash and calcium sulfate dihydrate, it can be seen in Figure 3 show that the smallest shrinkage limit value is found at a percentage of 0% palm shell ash and calcium sulfate dihydrate, namely 39.06%. The shrinkage limit value increases until it reaches 12% (56.17%). Meanwhile, the swelling value decreased as the percentage of the palm shell ash-calcium sulfate dihydrate mixture increased. The largest swelling value was at 0%, or 13.08%, after a 14-day soaking time, and the smallest swelling value was at 20%, or 0.57%, after a 1-day soaking time.

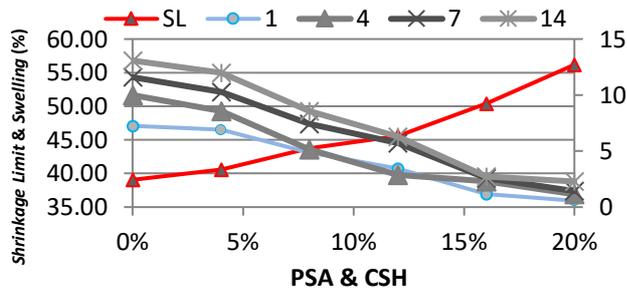


Fig. 3 Graph of the Relationship between Shrinkage Limit and Swelling with Variations in the Mixture of Palm Kernel Shell Ash and Calcium Sulfate Dihydrate

Increasing the shrinkage limit significantly affects the properties of clay soil by reducing swelling. A reduction in water content, followed by an increase in effective stress, causes soil volume to shrink; conversely, an increase in water content causes swelling. The higher the shrinkage limit, the smaller the percentage of swelling. The higher the shrinkage limit, the more difficult it is for the soil to undergo volume changes. The higher the shrinkage limit, the more water is required to achieve a volume change.

4. CONCLUSION

Based on the analyzed research data, it can be concluded that the swelling test results on clay soil show that with increasing percentages of palm shell ash and calcium sulfate dihydrate, the swelling decreases. However, with each variation in the mixture of palm shell ash and calcium sulfate dihydrate, the swelling value increases. The plasticity index value decreases, while the shrinkage limit value increases. The correlation between the plasticity index and the shrinkage limit on swelling is that the greater the plasticity index, the greater the swelling. Meanwhile, the greater the shrinkage limit, the smaller the swelling value that occurs.

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