The Effect of Curing Time on the Engineering Properties of Sawdust and Lime Stabilized Expansive Soils

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The Effect of Curing Time on the Engineering Properties of Sawdust and Lime Stabilized Expansive Soils

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I. INTRODUCTION

Pavement subgrade mainly consists of locally available soils, of which some of them are weak to support the upper layers of the pavement hence a major cause of pavement failures. These soils fail to support long-term pavement leading to pavement deterioration in terms of the development of cracks and potholes [1]. According to Fwa [2], the performance of any pavement depends upon the quality of the subgrade. A stabilized subgrade soil can provide a stronger pavement whereas a subgrade with poor engineering properties can result in inadequate pavement support, hence leading to a reduction in the design life of the pavement [3]. For that matter, the subgrade engineering properties need special attention because they influence the ability of the subgrade to resist force from the upper layers. If the load-bearing capacity of the subgrade is improved by any suitable means, then a lower thickness of road structure is needed, and eventually, road construction would be economical.

The subgrade soils with poor engineering properties include expansive clay soils. These soils possess threats to the construction of the pavement due to their low shear strength and high swelling characteristic [4]. In many cases, expansive soils have a high free swell index, and high plasticity index. According to Head [5], soils with free swell index less than 50% are less likely to show expansion properties, while the ones with swell index greater than 100% are susceptible to swelling under wet conditions. A plasticity index greater than 35% signifies that soil has high swelling potential [6]. According to Burmister [7], highly plastic soils begin with a plasticity index of 40. To overcome the problem of swelling and shrinking, the expansive soils are either compacted or stabilized by chemicals or other stabilizers like wastes. Considering the trees that are cut across the globe, large quantities of sawdust are being generated [8-9]. Stabilizers increase workability, reduce the plasticity index and increase the strength of the soil [10, 11,12,13]. According to Khan & Khan [14], about 10-13 % of the total volume of the wood log is processed into sawdust. Sawdust possesses little cementitious properties, but when blended with other materials having cementitious properties such as lime, their usage can yield better results [8,14,15]. According to Horisawa [16], dry wood consists of cellulose, lignin, hemicelluloses, and small amounts (5-10%) of other materials. These components possess some cementitious properties. In the current study, the assessment of the strength of subgrade stabilized with sawdust and lime was carried out. These materials were added at 6% (3% lime+3% sawdust) of dry soil weight. Both the treated and non-treated samples were cured for 0, 7, 14, and 28 days in order to study the effect of curing time on engineering properties. Unconfined compressive strength and CBR were conducted at all curing times to investigate the engineering properties of soil–sawdust-lime mixtures.

II. MATERIALS

A. *Expansive Soil*

The expansive soil used in this study was from Godong sub-district, Grobogan District, Central Java Province, Indonesia, along Semarang-Purwodadi road at STA 49 Km. Both disturbed and undisturbed sampling techniques were used while collecting the samples. Before usage, the soil samples were oven-dried at a temperature of 600°C.

B. Lime

The lime used in this study is calcium oxide (CaO), commonly known as quick lime. It was bought from the nearest hardware shop and then sieved through sieve No.40. Lime is prepared by burning limestone or calcium carbonate ($CaCO_3$) at elevated temperatures (between 850°C and 1200°C) driving away carbon dioxide, thus forming calcium oxide as shown in (1).

$$\text{Burning } CaCO_3(s) + \text{Heat} \rightarrow CaO(s) + CO_{2\,(g)} \quad (1)$$

C. Sawdust

Sawdust is a by-product that comes after cutting or pulverizing wood using a saw or any other blade in sawmill or lumbering industries. The sawdust used in the current study was acquired from the Woodwork Department, Politeknik Negeri Semarang (POLINES), Tembalang. Afterward, it was air-dried in an oven at a temperature of 600ºC, and then a selected sample was taken to the integrated laboratory, Universitas Diponegoro to determine the chemical composition of the sawdust sample. The sawdust used in this study was passed through sieve No.40 (0.841mm). According to the concept of stabilization, some of the total weight of the sawdust whose diameter is smaller than the soil diameter works as fillers, thus filling the void between each successive particles, and the sawdust particles with bigger diameter than that of the soil covers the particles, thus increasing the bond (see Fig. 1). The chemical components of sawdust were analyzed by Energy Dispersive X-ray (EDX) and found out that the major chemical constituents were carbon (61.9%), oxygen (37.6%), and small percentages of other compounds. The previous studies by Singh et al. [17], and Phonphuak & Chindaprasirt [18] also presents high carbon and oxygen contents in Sawdust (45% and 30% respectively), and (60.8% and 33.8%), respectively. The carbon units are linked together by molecular bond, a strong bond that helps in sustaining part of stresses generated as a result of shed loads on the soil.

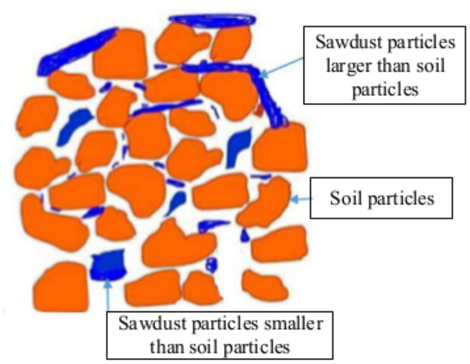

Fig. 1. Mechanism of sawdust to work as a soil filler material.

III. METHODS

All laboratory works were conducted in accordance to American Society for Testing and Materials (ASTM) standard procedures, as shown in TABLE I [19]. The soil samples were crushed using a rubber mallet into small sizes usually less than 4.75 mm sieve for compaction, CBR, and UCS tests, and less than 0.425 mm for Atterberg limit tests.

The tests conducted include; moisture content, Specific gravity to be used in the calculation of mass-volume relationship, Consistency limit (Atterberg limits), Free swell index (FSI) to measure the increase in volume of the soil with respect to the original volume, Grain-size distribution in order to group the particles into separate ranges of sizes, compaction test to obtain the optimum moisture content (OMC) and maximum dry density (MDD), CBR to determine the bearing capacity of the soil, and UCS to determine the unconfined shear strength of the soil. The CBR test was carried done in accordance to ASTM D-1883 procedures [20].

TABLE I. LABORATORY TESTS DESIGNATIONS [19]

Test	Designation
Moisture content	D-2216
Specific gravity	D-854
Consistency limits	D-4318
Hydrometer Analysis	D-422
Sieve Analysis	D-421
Standard Proctor's Test	D-698
Unconfined Compressive Strength Test	D-2166

IV. RESULTS AND DISCUSSION

A. Geotechnical Properties of Expansive Soil

The geotechnical properties of the used soil are presented in TABLE II. It was observed that the soil under consideration has 98.64% particles less than 0.075 mm, a liquid limit of 94.51%, and plastic limit of 30.55%, hence a plasticity index of 63.96%. According to Chen [6], soils with a plasticity index of 0-15 has low swelling potential, those with 10-35, medium swelling potential, 20-55, high swelling potential, and greater than 35%, very high swelling potential. This clearly shows that the soil under the current study is highly plastic clay soil with high swelling potential.

TABLE II. GEOTECHNICAL PROPERTIES OF THE SOIL UNDER CONSIDERATION

No.	Property	Quantity
1	Natural moisture content %	56.68
2	Percentage passing No. 200	98.64
3	Liquid limit %	94.51
4	Plastic limit %	30.55
5	Plasticity index %	63.96
6	Specific gravity	2.68
7	AASHTO soil classification	A-7-5
8	Free swell Index %	130
9	Maximum dry density g/cm^3	1.36
10	Optimum moisture content %	31.5
11	Unsoaked CBR at 100% MDD (%)	11
12	Unsoaked CBR at 95% MDD (%)	10
13	Soaked CBR at 100% MDD (%)	4
14	Soaked CBR at 95% MDD (%)	3
15	UCS (kg/cm^2)	4.576

B. Particle Size Distribution

The gradation for the five compositions (0% SD + 100% Soil, 3% SD + 97% Soil, 5% SD + 95% Soil, 7% SD + 93% Soil, and 3% Lime + 3% SD + 94% Soil is shown in TABLE III. It is observed that 0% SD + 100% Soil, 3% SD + 97% Soil, 5% SD + 95% Soil, and 7% SD + 93% Soil has 98.64% fine aggregates (silt and clay) and 1.36% course aggregates (sand and gravel), 55.32% fine aggregates and 44.68% coarse aggregates, 70.98% fine aggregates and 29.02% coarse aggregates and, 66.28% fine aggregates and 33.72% coarse aggregates. According to AASHTO classification system, the first, second, third and fourth compositions lie under A-7-5 group, and the general rating as a subgrade material is fair to poor. The fifth composition lies under A-2-7 group, and the general AASHTO rating is excellent to good [19].

TABLE III. RECAPITULATION OF GRAIN-SIZE DISTRIBUTION STABILIZED SOILS

Composition	Particle			
	Gravel	Sand	Silt	Clay
100%Soil+0%SD	0.00	1.36	45.64	53.00
97%Soil+3%SD	1.22	43.46	25.32	30.00
95%Soil+5%SD	0.00	29.02	60.98	10.00
93%Soil+7%SD	0.80	32.92	52.28	14.00
94%Soil+3%Lime+3%SD	2.96	69.20	14.84	13.00

C. Free Swell Index

The effect of sawdust on the free swell index of expansive clay soil is insignificant. The free swell index of the natural soil (0% SD + 100% Soil) is 130%, and the one of the stabilized samples with 3% SD, 5% SD, 7% SD, and 3% SD + 3% lime is 110, 140, 130, and 50% respectively. Soils with free swell index less than 50% are less likely to show expansion properties, while the ones with greater than 100% are susceptible to swelling under wet conditions [5]. Based on the current study, the FSI is greater than 100%, thus has high chances of soil expansion during the wet season. The mixture of 3% SD and 3% lime to 94% soil reduced the free swell index significantly; this really shows a reduction of expansion and swelling features.

D. Consistency limits

The liquid limit (LL) and plastic limit (PL) tests were carried out with different percentages of soil–sawdust mixtures. The effects of sawdust content on the liquid limit, plastic limit, and plasticity index (PI) for the sawdust- soil samples are seen in TABLE IV.

TABLE IV. THE VARIATION IN CONSISTENCY LIMIT FOR STABILIZED AND NON-STABILIZED SOILS

Composition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0%SD+100%soil	94.51	30.55	63.96
3%SD+97%soil	86.61	36.00	50.61
5%SD+95%soil	80.59	39.49	41.10
7%SD+93%soil	74.98	38.33	36.65
3%SD+3%Lime+94%Soil	58.78	42.76	16.01

It was observed the liquid limit reduced significantly from 94.56% for the non-stabilized soil to 58.78% after replacing the soil with 3% SD and 3% lime, with an increase in plastic limit from 30.55% to 42.76%, thus an overall decrease in the plasticity index. The same trend was seen in the study conducted by Bell [11] in stabilizing the soils with lime. According to Burmister [7], plasticity index ranging from 1-5 is slightly plastic, 5-10 low plastic, 10-20 medium plastic, 20-40 high plasticity, and greater than 40 very high plasticity. The soil-sawdust-lime mixture sample has a plasticity index of 16.01%, thus falling under medium plasticity soils. It is believed that the chemical reaction that occurred between sawdust, lime, and soil altered the size composition of the untreated soil that initially had a high liquid limit, thus reducing its plasticity index and increasing its strength and water stability [15].

E. Standard Proctor's Test

The optimum moisture content and maximum dry densities for the different compositions are presented in TABLE V. It was observed that the MDD decreases, while the OMC increases with the increase in the proportion of sawdust, and the composition of 3% SD + 3% Lime + 94% Soil also showed a similar trend. The decrease in the maximum dry density for the blend consisting of 3% lime and 3% SD could be the immediate reaction of sawdust and lime with soil that is attributed by flocculation and agglomeration of the particles. On the other hand, the increase in optimum moisture content (OMC) for the sawdust-lime stabilized specimen could be the absorption of a high amount of water by lime and sawdust due to hydration [13].

TABLE V. THE OPTIMUM MOISTURE CONTENT AND MAXIMUM DRY DENSITY OF STABILIZED SAMPLES

Composition	Optimum Moisture Content (%)	Maximum Dry Density (g/cm3)
0%SD+100%soil	31.5	1.36
3%SD+97%soil	32.0	1.259
5%SD+95%soil	35.0	1.236
7%SD+93%soil	36.0	1.196
3%SD+3%Lime+94%Soil	31.7	1.321

F. Unconfined Compressive Strength (UCS)

The unconfined compressive strength values for soil-sawdust stabilized samples are shown in Fig. 2. It was observed that the highest UCS achieved was 6.387 kg/cm2 at 3% SD + 97% Soil, thus being the optimum percentage of sawdust needed to increase on the strength of expansive soils. The UCS for the soil-lime-sawdust mixture for different curing periods is presented in TABLE VI and Fig. 3. The UCS values of soil-lime-sawdust treated soils are higher than the Soil-Sawdust treated soils. It is observed that a combination of lime and sawdust added a significant impact on the strength of the soils, especially the 28-day cured samples. The strength is obtained from the silica and alumina that are significant components of lime. These elements react with calcium to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH). CSH and CAH form the matrix that plays a vital role in the strength of lime treated soils. The matrix formed changes the gradation of the soil, for example; from a sandy, granular material to a hard, relatively impermeable layer with significant load-bearing capacity. The matrix formed is lifelong, durable, and significantly impermeable, producing a structural layer that is both strong and flexible [10].

TABLE VI. THE UCS VALUES FOR SAWDUST-LIME STABLISED SAMPLES DURING DIFFERENT CURING PERIODS

Curing time (days)	0	7	14	28
Unconfined Compressive Strength (kg/cm²)	7.14	7.35	10.44	13.48

It is seen in Fig. 3 that there was a low increase in UCS for the samples cured for 0 and 7 days while those cured for 14 and 28 days showed a tremendous increase.

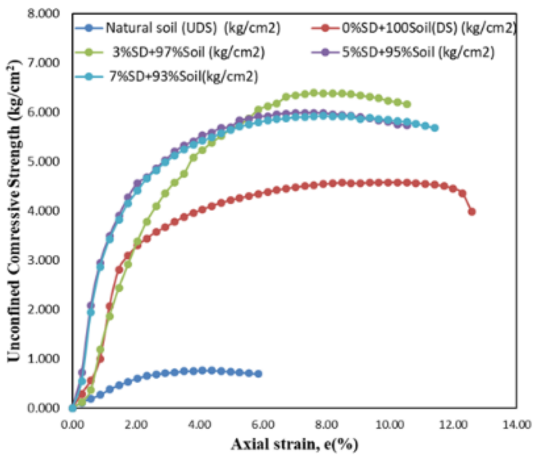

Fig. 2. UCS for different soil-sawdust mixtures.

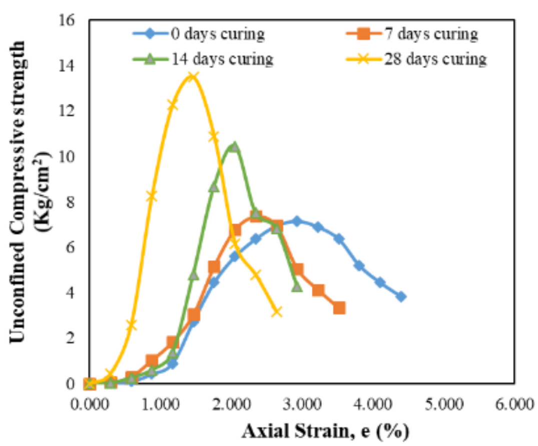

Fig. 3. UCS for 3% SD + 3% Lime + 94 % soil on different curing periods.

G. California Bearing Ratio (CBR)

The soil-sawdust-lime samples were cured for 0, 7, 14, and 28 days to determine the long term bearing capacity of the soil. Substituting the soil with 3% sawdust and 3% lime significantly improved the CBR of the soil. The variation of unsoaked and soaked CBR values for different curing periods is presented in TABLE VII and TABLE VIII. It has been noticed that the unsoaked CBR values of sawdust-lime-soil mixtures increased substantially with the increased curing periods. Strangely, some soaked CBR values for the lime-sawdust treated soils during the earlier curing periods are higher than the unsoaked values. The same scenario was reported by Amadi & Okeiyi [13] in stabilizing lateritic soil with both quick lime and hydrated lime. The reason for the increased CBR for the soaked treated specimens could be the formation of cementitious chemical compounds, that are similar to the ones of portland cement such as calcium–silicate–hydrates (C–S–H), calcium–aluminate–hydrates (C–A–H) and calcium–aluminum–silicate–hydrates (C–A–S–H) associated with renewed hydration of the lime and the pozzolanic reactions [12,13].

TABLE VII. THE CBR VALUES FOR THE UNSOAKED SPECIMEN (3% SD + 3% LIME + 94% SOIL)

Curing time (days)	**CBR values at different number of blows**		
	56	**25**	**10**
0	34	23	13
7	75	35	20
14	78	40	17
28	84	48	17

TABLE VIII. CBR VALUES FOR THE SOAKED SPECIMEN (3% SD + 3% LIME + 94% SOIL)

Curing time (days)	**CBR values at different number of blows**		
	56	**25**	**10**
0	37	32	13
7	50	39	18
14	51	43	15
28	41	38	9

V. CONCLUSIONS

The current study investigated the effect of curing periods on the strength of sawdust-lime stabilized expansive soil samples. Based on the analysis of the results, the following conclusions were derived;

1. The soil under study is highly plastic clay with high free swell index hence poor subgrade material.

2. The results of the UCS test revealed that lime-sawdust treated specimens experienced an increase in UCS with an increase in the curing periods with different magnitudes. At 0, and 7 days curing, the increase was low, while at 14, and 28 days of curing, the increase was significant.

3. The CBR values of sawdust-lime treated soils increased tremendously with the increased curing days, and the soaked CBR values for 0 day curing were higher than the unsoaked values at compaction of 56, and 25 blows, and then the same at 10 blows. For the rest of other curing days, the soaked CBR values are lower than the unsoaked values but still higher than the untreated soil sample.

Finally, it can be concluded that curing time created a significant influence on the engineering properties

(Unconfined compressive strength and California Bearing Ratio) of the soil-sawdust-lime specimens. This was noticed by the high values of UCS and CBR obtained.

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