Effects of Curing Time Using Crushed Coconut Shell (CCS) and Coconut Shell Ash (CSA) as Additive to Improve Lateritic Soils

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Abstract. Numerous constructions in Malaysia have encountered the issues where soil cannot fulfill the standard required specification due to the bearing capacity of soft soil is too weak to withstand traffic loading. Recently, there is a lot of defeats related to soil settlement and distorting of the structure effect by the inflated compressibility and low in shear strength of the soil. This research study on the effects of natural additives in crushed coconut shell (CCS) and coconut shell ash (CSA) to enhance the durability of lateritic soil for road pavement. The effects of curing time in the CCS and CSA admixture of soil is examined. Different proportions of 5% and 9% CSA with a constant 8% CCS were used to study the effect on lateritic soil. Series of preliminary tests were performed followed by engineering test of Compaction test in identification on optimum moisture content (OMC) and maximum dry density (MDD) followed by California Bearing Ratio (CBR) for curing day of 4 days, 7 days and 14 days of soil mixtures sample to investigate its enhancement to soil strength. Further review from the previous research has also been carried out and it is pointed out that by using natural CCS and CSA brushed up the soil load-bearing capacity due to the increment of CBR value obtained as compared to the normal mix. Hence, it can be concluded that the combination of natural additives CCS and CSA in the soil also have the capability to improve the soil strength and can be suggest to replace aggregates and cement for use in lateritic soil stabilization subject to road works.

1. Introduction

The road consists layers of subgrade, subbase, base course and wearing course. The main factor for the construction and design of highway projects is the presence of good in-situ soil [1]. Lateritic soils are in-situ soils that are highly weathered soils which take place in the tropical and subtropical climatic states. Certain lateritic soils in the natural state literally have the low bearing capacity and low in strength due to excessive content of clay. Hence, the stability and stiffness unable to covenant under traffic load primarily due to existence of the moisture [2]. Therefore, it generates pavement distress and slightly to foundation failure [3]. At the time when the natural lateritic soils were high plasticity clay, the plasticity of soil may result in crack destructions to road pavement, building substructures or any related construction projects.

For road construction, most of the lateritic soils obtain are within the classifications of A-2, A-6, and A-7 and an infrequent for lateritic soil classify in A-3 or A-5 [4]. Majority of the natural condition of lateritic soils are convenient for subbase, aside from the standard pavement base construction [5]. The research of soil stabilization for road construction is to improve soil durability by increasing the strength and reduction of plasticity index also its resistance towards weathering and soil erosion [6]. Designing
the road to fit the sub-standard site materials or replacing with a standard fill material method can be used to overcome the limitations in the availability of standard base course materials.

Increment of construction activities and industrialization have brought to the rapidly higher consumption of aggregate and cement. Both are getting exhausted and the high pricing due to local non-availability and insufficiency [7]. This research is an attempt to recycle the coconut which is the top five contributors to agricultural waste in Malaysia in order to reduce the use of conventional aggregate as pavement materials. The physical properties of coconut shells which are rigid and high carbon content had been usually used in the production of activated carbon. [8] stated that coconut shells showed positive physical properties improvement in terms of strength and workability. Hence, by considering the perspective of CCS and CSA to enhance the production of concrete and soil, the research is aim to analyse the CCS act as coarse aggregate and CSA act as cement respected to curing time was commenced with the intention to strengthen the lateritic soils. These also will help to alleviate the environmental pollution impact on the environment. Table 1 and 2 shows the chemical composition of coconut shell (CS) and coconut shell ash (CSA).

**Table 1.** Condition in dry basin of Coconut shell (CS) Compound [3]

| Compound       | Percent |
|----------------|---------|
| K₂O            | 45.01   |
| Na₂O           | 15.42   |
| CaO            | 6.26    |
| MgO            | 1.32    |
| Fe₂O₃ + Al₂O₃  | 1.39    |
| P₂O₅           | 4.64    |
| SO₃            | 5.75    |
| SiO₂           | 4.64    |

**Table 2.** Chemical Composition of CSA [9]

| Elemental Oxide | Percent |
|-----------------|---------|
| K₂O             | 0.83    |
| Na₂O            | 0.95    |
| CaO             | 4.98    |
| MgO             | 1.89    |
| Al₂O₃           | 24.12   |
| P₂O₅            | 0.32    |
| SO₃             | 0.71    |
| SiO₂            | 37.97   |
| Fe₂O₃           | 15.48   |
| MnO             | 0.81    |
| LOI             | 11.94   |
2. Materials and Method

2.1. Soils
The laterite soil was collected from one of a hill and meditation retreat known as Suling Hill in Mengkuang, Bukit Mertajam. The soil was dug out at the certain depth below the ground level. The laterite soils then oven dried at temperature of 110°C for 1 day. The dried soil sample were crushed to obtain the finest soil purposely for the engineering properties test as in Figure 1. Preliminary tests were carried out on untreated samples for identification and classification in accordance with BS1377[10].

2.2. Coconut Shell (CS)
CS was obtained from the groceries shop at Bukit Mertajam. The fibres surrounded the CS were pull out. The CS were crushed manually by a hammer and sieved to the selected sizes in the range between 3mm to 12mm (Figure 2). CS is one of the possible aspirant development as composite materials due to their high strength and modulus properties, good impact resistance, and presents better workability in coconut shells. As compared to normal aggregate, coconut shells have high characteristics in water absorption and moisture-retaining capacity [11].

2.3. Coconut Shell Ash (CSA)
CSA samples were supplied by Tiang Seri Global Venture, Selangor Darul Ehsan. The ashes were dried in the oven for about 3 hours to get rid of the moisture in the ash. Then, the CSA were allowed to cool down before sieve passing through 425µm BS sieve and preserved in the airtight containers to avoid pre-hydration of the ash. Figure 3 shows the CSA samples. Coconut shell ash which contains higher silica when concurrence with calcium will allow the cementing features by pozzolanic reaction [3]. The ratio of silica (SiO$_2$) to sesquioxides (Fe$_2$O$_3$ + Al$_2$O$_3$) is 1.43 showing the ash content compatible with the lateritic soil which generally the proportion between 1.3 and 2 [2].
2.4. Method of Testing

The preliminary tests were carried out on the sample of natural subgrade include particle size distribution, Atterberg limit test, moisture content and specific gravity for the aim of soil classification, then performing the engineering test of compaction test and California Bearing Ratio (CBR) on the controlled and modified soil sample. The crushed coconut shell (CCS) and coconut shell ash (CSA) on various proportions were added as a modified sample shown in Table 3. The proportion of CCS with a constant 8% and mixed thoroughly with different percentages of 5% and 9% CSA by weight of natural soil sample. The CBR test for soaked cured for 4 days, 7 days, and 14 days were performed to assess the strength of soil mixtures. Every procedure was carried out in line with that required in BS 1377 [10]. Table 4 shows the abstract of the preliminary results of the laterite soil.

Table 3. Proportion of Soil Sample, CCS and CSA

| Sample | Proportions of Sample (%) | Curing Period (Days) |
|--------|---------------------------|----------------------|
|        | CCS | CSA | Soil |                    |
| S1     | 0   | 0   | 100  | -                   |
| S2     | 8   | 5   | 87   | 4,7,14              |
| S3     | 8   | 9   | 83   |                      |

Table 4. Preliminary Results of Laterite Soil

| Engineering Properties | Values     |
|------------------------|------------|
| Soil Classification    | well graded silty SAND |
| Moisture content (%)   | 21.15      |
| Specific gravity (Mg/m³) | 2.60       |
| Liquid Limit (%)       | 70.0       |
| Plastic Limit (%)      | 25.2       |
| Plasticity Index (%)   | 44.8       |
| Maximum Dry Density (Mg/m³) | 1.63   |
| Optimum Moisture Content (%) | 22.77   |
| California Bearing Ratio (%) | 21.2     |

2.5. Methods on Systematic Review

Due to the worldwide pandemic of COVID-19, an initiative of adding the review of previous studies which take up 20% of the whole research has been taken to analyses the performance of additives. This objective is included in this study in order to add research value to strengthen the findings of the
experimental works. This review is to conform the performance of CSA and CCS as an additive to subgrade soil. Hence, this part explained on the systematic review process and data abstraction and analysis of the previous studies which are related to the present research. The review methods were conducted using manual searching efforts on several established sources such as Google Scholar, Academia.edu and Science Direct to obtained more relevant articles. For instance, Google Scholar has published over 50 000 articles related to soil stabilization meanwhile Academia.edu suggests over 1000 publications on soil stabilization using agricultural waste studies. The following in Figure 4 is the systematic review proceeding for selecting the articles.

i) Identification
Consists of three main stages in selecting a number of applicable articles to conduct the current research. Via identification of the main keywords followed by the searching on the related topics, 11 articles were retrieved which only focused on the stabilized soils by using natural additives coconut.

ii) Screening
Removed the duplicate articles and timeline published less than year 2015. Total of 1 article was excluded due to this criterion.

iii) Eligibility
In this stage, the titles, abstracts, and the main contents of the research studies were examined. This is to certify on the fulfilled criteria related to the present study of using natural additives coconut shell ash to stabilized subgrade soil.

iv) Data abstraction and analysis
After the following process, the remained selected of 4 articles were analyses and the pattern of the strength data was abstract placed in the table for better systematic review and comparisons.

Figure 4. Systematic Review Procedure

3. Result and Discussion
The research results obtained were examined and assessed in the modified samples of natural admixture of CCS and CSA for the changes of OMC and MDD of the sample and CBR strength correlated to curing time.
3.1. Effects of CCS and CSA on the OMC and MDD of Soils

Figure 5 illustrates the pattern of dry density against moisture content for the controlled and modified samples. The pattern showed irregularly shaped compaction as it has the 1 1/2 peak graph. This is due to a dominant percentage of plate-like colloidal particles in soil mixing. In addition, irregular shapes happened as the lateritic soil contains more than 50% of sandy soil specimens and the liquid limit of the soils is in a range of 30% to 70%. Besides that, the soil samples may bring unpredictable combinations whenever montmorillonite was present, which was due to catalytic processes in the hydrated aluminium silicate (Al₂O₃ + SiO₂). This conveys the high swell-shrink potential of soils. Proven by [12] that data contains 50% or greater of sand will result in the irregular shaped compaction curved. It is because the small amount of montmorillonite present could yield a liquid limit of 51%.

![Figure 5. Pattern of Dry Density against Moisture Content for Controlled and Modified Samples](image)

The controlled sample of lateritic soil in Figure 6 had optimum moisture content (OMC) of 22.77% and maximum dry density (MDD) of 1.6 Mg/m³. Meanwhile, for the modified samples of additional percentage additives 5% CSA + 8% CCS, it reduced the OMC to 21.8% as well as decreased the MDD to 1.52 Mg/m³. The value of OMC and MDD decreased with the increased percentage CSA. The decreases of OMC were due to the depletion of water resulting in low hydration. As no water movement in modified soil sample was allowed, the water is used up in the hydration reaction until slightly left to saturate the solid surfaces and therefore the relative humidity within the mixture decreased [5]. Meanwhile, decreases in MDD as the void between the particles is being filled by the finest particle which is CSA. Hence, it can be concluded that CSA is a pozzolana since the CSA have a greater minimum total percentage requirement of 50% of SiO₂, Fe₂O₃, and Al₂O₃ in accordance with ASTM C 618 requirements [2][13]. Besides that, the pattern showed that the stabilized soils had a smaller increase in resilient modulus which acts as an indicator in contribution to surface deflection. However, all properties of soil which may affect the performance of pavement are not represented via resilient modulus [14].
3.2. Effects of Curing Time using CCS and CSA on Load Bearing Capacity of Soils

Each mixture was cured for 4, 7, and 14 days to produce the time-strength graph as shown in Figure 7. The stiffness of modified soil with 9% CSA + 8% CCS drops after soaking from 4 days to 14 days. Meanwhile, for 5% CSA + 8% CCS, the rigidity decreases after 7 days of curing period. By comparing with the additives CSA and CCS, mixed with 9% CSA + 8% CCS induce to highest CBR stiffness development. The increment of CBR value might be due to the gradual formation of cementitious compounds in the lateritic soil by the reaction of CaOH and CSA. Based on the visual observation, the results indicate that the stiffness of soil with a higher percentage of admixture decreases when cured over longer periods. This may due to loosening the cementitious effect by additive at a high level in the presence of moisture. This indicates that the maximum hydration effect takes place at 4 days of curing whereby at this time the reaction of admixed soil reaches its optimum strength. However, this study can prove that the increase in the addition to CSA and CS may provide room for soil enhancement. It is agreeing with the statement of CSA which contains a high percentage of siliceous material helps to facilitate the soil stabilization. This finding supported by previous research on fly ash and rice husk ash showed that the stabilized strength depends on the availability percentage of silicon and aluminum oxides [15].

![Figure 6. Variation of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of Different Soil Mixtures](image)

![Figure 7. The CBR Strength Value against Different Percentage of Admixture](image)

3.3. Previous Research on the Pattern of CBR value for laterite soil admixed with CSA

Several studies have been carried out on the previous research related to the pattern of the CBR strength value of soil. In these circumstances, it clearly indicates that a higher percentage of CSA could lower the CBR strength values of the soil [9][16-17]. It is found that the ashes contribute to the stiffness of
soil based on differences in water content. As the optimum moisture content gets higher, the value of CBR stiffness tends to decrease. Proven by the research [16] stated on CSA do absorbs more moisture when added to soil at which might be required for the pozzolanic reaction. It is remarkable that soil with higher water soil identity, the hydration process may be slow down due to inadequate moisture content which eventually could affect the final strength of the soil. Hence, it clearly stated that higher water content resulting in lower strength. Interesting to note that the similar proportion of 4% CSA being used by both researchers [7-8], but it can be explained that the addition of lime stabilization in [9] gave more impact on the soil rigidity compared to calcium carbide residue (CCR) studied by [16] as the lime diffuse through the soil hence it generates the greatest effect on the plasticity which resulting into remarkable strength. Moreover, increasing days of curing time, increase the strength of soil [16]. [18] deduce that for the first 7 days of curing, the strength of stabilized soil increases rapidly then it starts to increases slowly onwards.

### Table 5. Previous Research Related to Strength of Stabilized Soil

| Author | Soil - Admixture Combination | Major Geotechnical Properties Tested | State before stabilization | Effect after Stabilization |
|--------|-----------------------------|--------------------------------------|---------------------------|---------------------------|
| [8]    | Expansive soil + 4% Calcium carbide residue (CCR) + 4,9,14,19% Coconut shell ash (CSA) | Compressive Strength Test (UCC), curing 3 days and 7 days | 0.8 kg/cm² | UCC: 4%CCR + 4%CSA: <br> 3 days: 4.36 kg/cm² <br> 7 days: 9.02 kg/cm² <br> UCC: 4%CCR+19%CSA:<br> 3 days: 1.45 kg/cm² <br> 7 days: 2.00 kg/cm² |
| [16]   | Laterite soil + 3-12% coconut shell ash (CSA) | California Bearing Ratio (CBR), Soaked (4 days) and Unsoaked | Unsoaked: 22.16% Soaked: 11.29% | Unsoaked: 13.29% at 12% CSA Soaked: 3.14% at 12% CSA |
| [7]    | Laterite soil + 4%,8% Lime + 4% Coconut shell ash (CSA) | California Bearing Ratio (CBR), (cured for six days unsoaked, immersed in water for 24 hours) | CBR: 7.90% UCS: 57.30 kN/m² | CBR: 4%lime + 4%CSA: 49.70% UCS: 4%lime + 4%CSA: 242.89 kN/m² |
| [19]   | Laterite soil + 2-10% Lime + 2-10% Coconut shell ash (CSA) | California Bearing Ratio (Unsoaked) Unconfined Compressive Strength (UCS) | CBR: optimum 6% CSA + 6% lime: 66.4% UCS: optimum 4% CSA + 4% lime: 442 kN/m² |}
3.4. Comparison Between Previous Studies and Experimental Data

The majority of the research will be preferred on the combination of coconut shell ash with chemical additives to enhance the expansive soils. The chemical additives especially when using lime as stabilizers, can enlarge the soil particle size through a diminishing of plasticity index, cementation and reduce the shrinking-swelling prospective. Furthermore, the cemented base additives were frequently used as a component of pavement. Therefore, based on Figure 8, the CBR values gives a great impact before and after stabilization as the untreated laterite soil is 7.9% up to 49.70% when stabilizing with 4% lime + 4% CSA[9]. But not majority of soil shows an improvement when using lime additives. It must highlight that the soil mixtures properties depend on the type of soil, percentage additives, and curing state.[17] had a decrease in CBR soaked values at 4 days from 11.29% to 3.14% when admixing with 12% CSA. It can be concluded that CSA actually cannot be stand alone as the CSA needs to mix with other additives to enhance the soil stiffness. However, the stabilized soil is showing a good potential to act as material for subbase course in the construction of road pavement as it shows an improvement in the CBR value.

On the other hand, as compared with this research experimental data, combination natural additives 9% CSA + 8% CCS which act as cement and aggregates respectively gives the CBR value of 28% when cured in 4 days. However, this also shows the positive enhancement of soil stiffness. The environmental consideration is suggested as the chemical additives can assemble a large amount of carbon dioxide produced during the construction phase. The chemical compositions contain in the coconut shell such as CaO when having a combination with water also may help in soil enhancement as the formation of calcium hydroxide is mainly used in cement[20]. At the same time, the agricultural wastes of coconut shells are much cheaper as compared to the other cementing agents, hence contributing to the economic practicability of highway projects.

![Figure 8. Comparison of Previous Study on CBR Value Before and After Stabilization](image-url)
CSA improves the soil strength of the lateritic subgrade. By using CSA and CCS as an additive in this research, there will be remarkable depletion of fines content of the soil. Besides, it may be resulting in the reduction in plasticity characteristics of soil due to transition from high plasticity to intermediate plasticity followed by low plasticity. Greater than 9% CSA with 8% CCS will make another increment of CBR strength value. Concerning the curing time duration, the stabilize soil strength will be optimum at 4 days. This result is contradicted to [16] as in their study the combination of admixtures between CSA and chemical agent namely CCR shows a good relation at 7 days of curing time. Therefore, it can be deduced that by using natural additives such as CCS and CSA, the longer curing periods do not significantly influence the soil CBR value since the stiffness is highly influenced by the proportions and chemical composition of the additives used.

4. Conclusion and Recommendation
The physical properties of soil can affect the improvement of soil strength. According to the AASHTO system, the sample of lateritic soil was classified as A-2-7(0) and well graded silty SAND of high plasticity. CSA can be classified as pozzolanic materials. An increment of CBR stiffness due to the evolution of cementitious compounds by reactions of CaOH and CSA. Then, a higher percentage of additives of CSA with constant 8% CCS decreased when cured for a longer period. Thus, maximum hydration effects expected to take place at 4 days curing for the admixture soil reaches optimum rigidity. The admixture of CSA and CCS gives a great impact performance to soil enhancement on the strength, durability, moisture absorption. To conclude, the CCS and CSA in the soil have the capability to improve the soil stiffness whereas longer curing periods on the admixtures of CCS and CSA to soil did not significantly affect its rigidity. Combinations of natural additives CCS and CSA can be suggested to replace aggregates and cement for use in soil stabilization subject to road works. Further researches are requiring before implementing practical applications. There are several recommendations that can be executed to facilitate the study.

- Use the standardize of one size cement-like coconut shell ash (CSA) to assess the effectiveness reactions of the CSA in soils.
- Have the equally distributed quantity of CCS in the soil during the compaction test.
- Considering the compaction properties and energy used to enhance the strength of modified soil.
- Combination of greater than 9% CSA with constant 8% CCS should be conduct to obtain a greater stiffness of lateritic soil to be apply as subbase course materials in road construction.
- Stabilize in different soil types in order to analyse the reactions of CCS and CSA towards the strength to fulfill the guidelines and standard JKR specifications.

5. References

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