Effectiveness of crushed coconut shell and eggshell powder to act as subgrade stabilizer

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Abstract. In Malaysia, the productions of waste from various sources keep increasing annually. This problem can cause our nation to face serious problem regarding with the process in handling waste handling process at landfill. By recycling agricultural waste is the one of effective method to reduce the waste damping on landfill. The agricultural waste such as eggshell and coconut shell not commonly being used as stabilizing material as lime and cement in pavement design, but the mineral composition contain shows their own ability to strengthen the weak subgrade soil. Thus, the aimed for this study is to investigate the effectiveness mixture of eggshell powder (ESP) and Crushed Coconut Shell (CCS) on soil performance for subgrade layer. The combination of constant 3% ESP with the various percentage of CCS, 2%, 4%, 6% and 8% is evaluated by conducting Standard Proctor Test (SPT) and California Bearing Ratio (CBR) test. The results obtained shows the maximum CBR value achieved at 4% of CCS along with constant 3% ESP.

1. Introduction
Subgrade layer is a natural soil that functioning as a foundation in design pavement which receives the stresses from above layers. This layer is more important by considering for long term condition, cost, and provided thickness layer. This is because all pavement layers need their ultimate support from the underlying subgrade [1]. Weak subgrade layer should be avoiding if possible because it can influence on overall pavement design and performance. Thus, there are several techniques that can be used to strengthen the weak subgrade layer. The common method to stabilize soft subgrade materials is to replace the soft soil with higher strength materials such as crushed rock which can increase the subgrade performance. To stabilize subgrade soil commonly used chemical stabilizer such as lime or cement which can contribute to increase soil strength due to pozzolanic reaction between soil and lime. The problem arises when using chemical stabilization is increasing in air pollution due to emission of gasses carbon dioxide from cement and lime to surrounding which is not environmentally friendly.

Instead of using chemical stabilization, there are method that suitable to be used which eco-friendly to the environment and reduce cost of implementation. Agricultural waste can be used as stabilizer to stabilize subgrade layer. By using recyclable waste its help in reducing the waste production at landfill rather than being economical to surrounding.

The common waste materials that used to improve the quality of pavement construction are such as ash, scrap tire, fly ash, plastic waste and iron or steel slag [2]. The combination between eggshell
powder and crushed coconut shell can effectively to be used as soil stabilizer. By replacing eggshell powder with common stabilizer such as lime can reduce the environmental hazard while the crushed coconut shell suitable as replacement of conventional pavement materials (aggregate) which is high resistance for abrasion and impact.

2. Materials and Methods
The main objective in this study is to analyse the properties of laterite soil and to identify the effectiveness of combination between agricultural wastes which are crushed coconut shell and eggshell powder on soil performance.

The laterite soil used in this study located at Taytex Estate at Bukit Lembu, Sungai Petani, Kedah. The CCS was collected at the groceries shop nearby UiTM Pulau Pinang. The size of CCS being used is at passing 14 mm and retained at 10 mm sieve size. The size was selected based on a study by [3] found that the coconut shell has a potential to use as replacement for conventional aggregate which can improve in environmental protection and cost reduction measure. The crushed coconut shell also is suitable as soil stabilizer due to its ability which good in durability, high toughness and abrasion resistance as stated by [4]. This is because coconut shell has good weather resistant thus it is suitable to use as construction materials [5]. Besides, it has no economic value and its dispose process is costly and will cause environmental problem [6]. Table 1 shows the properties of CCS found by [7] which is use as a reference to facilitate this study.

| Physical and Mechanical Properties | Value |
|-----------------------------------|-------|
| Moisture Content (%)              | 4.2   |
| Water Absorption(24 hours) (%)    | 24.0  |
| Specific Gravity (Mg/m³)          | 1.4   |
| Impact Value (%)                  | 8.15  |
| Crushing Value (%)                | 2.58  |
| Abrasion Value (%)                | 1.63  |
| Bulk Density (kg/m³)              | 55.0  |
| Shell Thickness (mm)              | 2-8   |

The eggshell was collected at food court Kristal in UiTM Pulau Pinang. The size of eggshell must be into powder shape for use as replacement for soil stabilizer like lime since its contained similar mineral composition with lime. The similarities of chemical composition between lime and eggshell powder show that ability of eggshell powder to replace lime in stabilization process [8]. Eggshell is one of agricultural wastes that can be used as soil stabilizer since its chemical composition is rich source of lime, calcium and protein [9]. The Table 2 shows that the chemical properties of eggshell as carried out by previous researcher.
Table 2. The chemical composition of eggshell [10].

| Elements  | Percentage by Mass (%) |
|-----------|------------------------|
| CaO       | 50.7                   |
| SiO₂      | 0.09                   |
| Al₂O₃     | 0.03                   |
| MgO       | 0.01                   |
| Fe₂O₃     | 0.02                   |
| Na₂O      | 0.19                   |
| P₂O₅      | 0.24                   |
| SrO       | 0.13                   |
| NiO       | 0.001                  |
| SO₃       | 0.57                   |
| Cl        | 0.08                   |

In order to ensure the homogenous mixture or the uniformity for the mixture, the eggshell was mixed with soil first followed by crushed coconut shell. In this study was used constant 3% for eggshell powder that were mixed with increment percentage of crushed coconut shell which are 2%, 4%, 6% and 8%. Table 3 shows that the portion of soil sample, crushed coconut shell and eggshell powder that used for each testing.

Table 3. Proportion of admixture in soil sample.

| Sample | Laterite Soil (%) | Eggshell Powder (%) | Crushed Coconut Shell (%) |
|--------|-------------------|---------------------|---------------------------|
| 0      | 100               | 0                   | 0                         |
| 1      | 95                | 3                   | 2                         |
| 2      | 93                | 3                   | 4                         |
| 3      | 91                | 3                   | 6                         |
| 4      | 89                | 3                   | 8                         |

The soil sample is categorized as disturbed sample since process of collecting using backhoe to excavate at a depth 1 to 1.5 meters below the ground surface. The sample are then placed in air tight bag to maintain its environmental condition. The collected soil sample was transferred into laboratory and placed into oven dried at 105 ºC for 24 hours. After that, the soil sample was crushed using rubber hammer for finer grain size before ready to be used for testing.

The coconut shell was cleaned, and oven dried before being crushed. It was also crushed using hammer until it can pass through 14mm sieving size and retained at 10 mm. The size of crushed coconut shell was chosen based on the potential of coconut shell itself to replace conventional aggregate in subgrade layer.

It was cleaned and oven dried before being crushed. The crushed eggshell need to be blend and grinding until become powder in order to pass through 0.0425 mm sieving size. The size of eggshell must be into powder shape for use as replacement for soil stabilizer like lime since it’s contains similar mineral composition with lime.

3. Results and Discussion

The soil properties were tested at early stage for untreated sample and followed by the main laboratory works were tested by using admixture of CCS and ESP to identify the engineering properties of soil sample.

The properties of soil sample were tested by referring the British Standard guideline and the result are presented as tabulated in Table 4.
Table 4. Soil properties before stabilization.

| Soil Properties                  | Value |
|----------------------------------|-------|
| Soil Classification              | Silty SAND |
| Specific Gravity Mg/m³            | 2.56  |
| Optimum Moisture Content, OMC (%) | 16.13 |
| California Bearing Ratio, CBR (%) | 10    |

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values can be determined by performing the Standard Proctor Test conforming to the procedure in BS 1377-4-1990. Table 5 shows the analyse data for OMC and MDD values for soil testing with various percentages of admixtures.

Table 5. OMC and MDD values for soil samples.

| Sample                  | OMC (%) | MDD (Mg/m³) |
|-------------------------|---------|-------------|
| 0% ESP + 0% CCS        | 16.13   | 1.865       |
| 3% ESP + 2% CCS        | 16.93   | 1.860       |
| 3% ESP + 4% CCS        | 17.44   | 1.847       |
| 3% ESP + 6% CCS        | 18.06   | 1.800       |
| 3% ESP + 8% CCS        | 18.44   | 1.785       |

Figure 1 shows the relationship between OMC values and percentage of additive materials. The graph presented the increment OMC value as increase in addition of CCS. The graph represents the result of OMC which keep increasing as increasing percentage of CCS. This increment in OMC value can be justify that the crushed coconut shell has high ability in water absorption and can use directly as replacement of conventional aggregate without any further treatment except for water absorption test as stated by [11].

Figure 1. Optimum Moisture Content (OMC) vs percentage of additive materials.
The graph in Figure 2 shows the relationship between MDD values and percentage of additive materials. The increment of addition percentage of CCS causes the reduction in MDD value.

This result complies with a study by [12] as the percentage of eggshell increase, the optimum moisture content will increase and the Maximum Dry Density value will decrease. The inverse trend between OMC and MDD of the mixtures is deduced due to the increasing volume of CCS and inclusion of ESP, the surface area of the particles is also enlarged which requires more water to lubricate the entire matrix of the mixture to complete the chemical process of hydration and exchange actions that leads to strength gaining.

The CBR test was conducted to identify and characterize the strength and bearing capacity of subgrade in pavement design works. Table 6 shows the CBR value for two conditions which are soaked and unsoaked condition. Soaked CBR test is used to measure the soil strength in wet condition which can be classify as critical condition compare to unsoaked condition. This condition is where the soil sample is soaking in water for 4 days before commencing the test.

**Table 6. California Bearing Ratio (CBR) value for unsoaked and soaked condition.**

| Sample                  | Unsoaked Condition | Soaked Condition |
|-------------------------|--------------------|------------------|
| (Control Sample)        | 10.39              | 5.26             |
| 0% ESP + 0% CCS         | 10.9               | 17.53            |
| 3% ESP + 2% CCS         | 15.16              | 20.86            |
| 3% ESP + 4% CCS         | 7.14               | 15.28            |
| 3% ESP + 6% CCS         | 5.64               | 15.03            |

The graph in Figure 3 indicates the increment CBR value for both condition but soaked condition has the highest reading compare to unsoaked condition. It shows the CBR values are increase from
10.9% to 15.16% for unsoaked condition and increase from 5.26% to 17.53% for soaked condition with the increment percentage of CCS from 2% to 4%. However, it was found that the CBR value for both conditions start to decrease with the increment percentage of 6% to 8%.

![Graph showing comparison between CBR value of soaked and unsoaked condition.](image)

**Figure 3.** Comparison between CBR value of soaked and unsoaked condition.

The increase of CBR value for soaked condition is related to a study by Anoop [8] about the presence of hydrostatic pressure during wet condition is supposed to decrease the soil strength but due to addition of small amount of eggshell powder helps in increasing the pozzolanic reaction that caused higher impact on soil strength. This statement is supported by a study which discovered that optimum CBR value achieved at 3% of addition eggshell powder in clay soil type [13]. There is another study [14] which conforms to this result as they found that the addition of small amount of eggshell powder helps in increasing the pozzolanic reaction that caused higher impact on soil strength.

On the other hand, higher value in soaked condition was found to agree a study by [15] on stabilization of expensive soil using cementation material like lime as it revealed that using this kind of stabilizer can increase the compressive strength after 28 days of curing time. This shows that the treated soil can resist impact during ponding condition and that can relate with the CBR value in soaked condition which is higher compare to unsoaked condition. Based on the presented data, it is shown that optimum percentage of 4% CCS is suitable in both conditions which had fulfilled the JKR requirement for subgrade layer presented in Table 7. Soaked condition had achieved 20.38% of CBR value which is categorize as SG3 while for unsoaked condition fulfilled the JKR requirement at SG2 with 15.16% of CBR value. SG 2 and SG3 is used for road pavement designed for large volumes of traffic (Traffic Classes T4 and T5).

| Sub grade category | CBR (%) |
|--------------------|---------|
| SG1                | 5-12    |
| SG2                | 12.1-20 |
| SG3                | 20.1-30.0 |
| SG4                | >30.0   |

**Table 7.** Classes of subgrade strength based on CBR value.
4. Conclusions and Recommendations
Experimental study has been carried out to determine the effectiveness of crushed coconut shell and eggshell powder to act as subgrade stabilizer for a soil sample taken from a prescriptive site. The sample taken from Taytex Estate at Bukit Lembu area can be classified as Silty SAND. This is due to high in percentage of sand which is 85% and 15% of silt. The natural moisture content of soil sample is 16.22% while the specific gravity of soil is 2.56 Mg/m³. The optimum moisture content (OMC) obtained in this study was increased as the percentage of admixture increased. This increment can be justified as due to ability of coconut shell which is high in water absorption. The highest CBR value obtained was 20.86% at 4% of crushed coconut shell for soaked condition. The improvement in soil strength is because of the good interaction between eggshell powder and crushed coconut shell in soil sample. The constant 3% of eggshell powder is capable in binding the soil particle due to presence of lime especially in critical condition. Therefore, the optimum mixture was found to be at 4% of crushed coconut shell and constant 3% of eggshell powder as it represents the maximum CBR value in engineering test. In a conclusion, these natural waste materials, CCS and ESP is found to be potentially react as additives materials to the subgrade layer to increase the CBR value.

The recommendations that can be made from this study is to vary the size of CS and its shape such as in powder shape for better reaction with soil. Next, the percentage of eggshell can be more vary in order to find the most suitable percentage and also the optimum strength for subgrade soil.

Acknowledgments
The author would like to express special thanks of gratitude to the Assistant Engineer; Mr. Mohammad Azrul Aswad for helping in laboratory exercise and the author also would like to acknowledge Universiti Teknologi MARA (UiTM) Cawangan Pulau Pinang for providing facilities to support this research work.

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