Agriculture land development using shell husk as recycle aggregate

Siti Hanggita Rachmawati[1,3], Zakaria Hossain[1*], Jim Shiau[2]

(1. *Department of Environmental Science and Technology, Graduate School of Bioresources, Mie University, Japan*;
2. *School of Civil Engineering and Surveying, University of Southern Queensland Springfield, Brisbane-Australia*;
3. Faculty of Agriculture, University of Sriwijaya, South Sumatera-Indonesia*)*

Abstract: Effective ground improvement technique is normally needed in improving agriculture land condition. This is to accommodate agriculture activities which have operational loadings due to tractor or rice transplanter. The use of soil - shell husk - cement combination is considered as one of the possible ground improvement techniques and it is environment friendly. In this study, several combinations of waste shell husk and cement are investigated for its effect on soil shear strength and bearing capacity. Specimens containing 10% and 20% of waste shell husk along with 2%, 4%, 6% cement were tested using California Bearing Ratio (CBR), Direct Shear Test (DST) and Unconfined Compressive Strength (UCS). Test results show that the addition of shell husk and cement typically improves the engineering properties of the soil. It is concluded that the use of soil - shell husk-cement combination for ground improvement is an effective method for agriculture land development.

Keywords: waste, shell husk, ground improvement, CBR, direct shear test, UCS

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1 Introduction

Agriculture activities such as equipment mobilization, transportation of agriculture matter (fertilizer, seed and pesticide) or even walkway for people and animal are essential consideration of land development. To conceive the agricultural land development process, comprehension of intricate properties and variable characteristic of soil is needed. Existing soil condition at any particular site might be not pertinent for intended purpose of use. Other problems in agriculture land may include crack during dry season and muddy soil during rainfall season. Further technologies are necessary to fulfill land development achievement.

Ground improvement techniques are often used to improve the properties of soil in terms of their bearing capacity, shear strength, settlement characteristic and drainage (Hirkane et al., 2014). They are widely used in a large scope of construction such as industrial, commercial, housing projects and infrastructure construction for dams, tunnels, ports, roadways and embankments (Hirkane and Salunke, 2014). There are many different types of ground improvement techniques, which can be tailored to the natural condition of soil and economical aspect in order to achieve its effectiveness and efficiency. Stone columns is one method of ground improvements for both cohesive and cohesion less soil which give an ideal opportunity to use recycle aggregate (Egan and Scolombe, 2010). Recently recycle aggregate has recently been used in all over the world to reduce project budget and protect environment. Large amount of shell husks in all over the world are abandoned and they are needed to be handled seriously (Hossain, 2013).

Shell husk is composed mainly 95%-99% (by weight) of $CaCO_3$ that potentially convert to CaO for reinforcing the soil or binding the material (Park, 2014; Motamedi, 2015). Shell husk has benefit to decrease investment cost

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*** Corresponding author:** **Prof. Zakaria Hossain,** Mie Ken, Tsu Shi, Kurima Machiyacho, Graduate School of Bioresources, Mie University, 514-0102, Japan. Email: zakaria@mie-u.ac.jp. Tel: +81592319578, Fax: +81592319578.

and is suitable for agriculture condition due to light weight material (Hossain 2013, Barbachi et al., 2017). Previous study using direct shear test showed the engineering properties of soil is increased when the soil is combined with 10% and 20% shell husk (Rachmawati and Hossain, 2017). One possible technique to further enhance soil-shell husk material properties is to use cementing material such as ordinary Portland cement. Cement is one of the soil stabilizing agents being used widely, due to its quick process. It does not need mellowing time and provides a non-leaching platform to stabilize soils (Sariosseiri and Muhunthan, 2009). Application soil-cement with nominal dosage of cement also has significant contribution to environment and it is cost-effectiveness. In Japan, many terraces lands use cement treated soil for making new cultivation paddy fields from unused land (Hossain and Sakai, 2008). Figure 1 shows a typical application of soil-shell husk-cement combination in agriculture land.

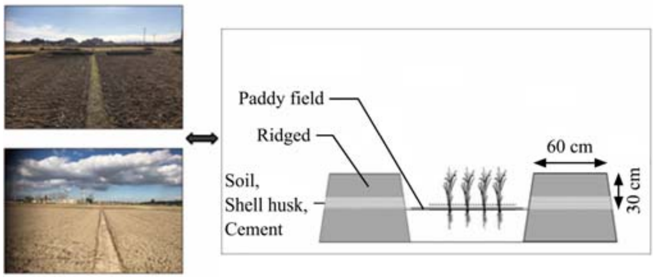

Figure 1 Paddy ridge in Japan

In this paper, three commonly used strength tests are adopted to investigate the strength properties of soil - shell husk - cement. They are the California Bearing Ratio (CBR), the Direct Shear Test (DST) and the Unconfined Compressive Strength (UCS). Sandy soil with 10% and 20% shell husk are combined with 2%, 4% and 6% cement and all specimens are tested after seven days curing.

2 Testing materials and methods

In this research testing specimens are consisting of soil, shell husk and cement. The soil sample was collected from Shiratsuka port, Tsu, Mie Prefecture, Japan. From the laboratory test result based on Unified Classification System, it shows that the sand has the highest part of this soil. Figure 2 shows the particle size distribution of sandy soil. In this chart, the soil consists of approximately 26 % gravel, 7% granule, 13% coarse sand, 29% medium sand, 10% fine sand, 11% silt and 4% clay. Table 1 shows the other properties of the soil.

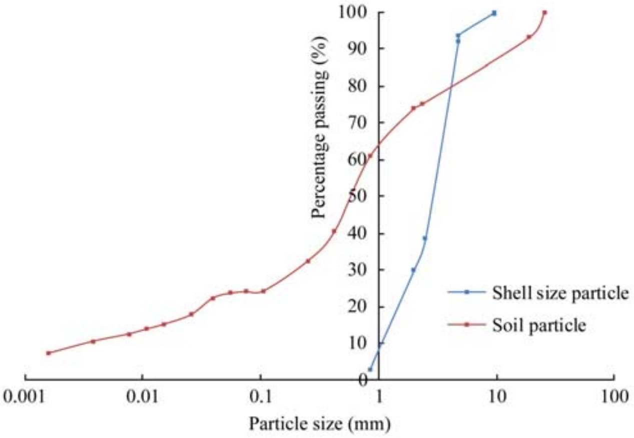

Figure 2 Particle size distribution curve

Table 1 Properties of soil and shell husk

Particles	Parameters	Values
Soil particle	Dry density (ρ_d)	1.80 g cm^{-3}
	Optimum water content (W_{opt})	13.29%
	Specific gravity (ρ_s)	2.589
	Cohesion (c)	1.52
	Angle of internal friction (φ)	23.23
	Sand > 75 μm	85.00%
	Silt >5-75 μm	11.00%
	Clay <5 μm	4.00%
	Liquid limit	39.00%
	Plastic limit	26.80%
	Plasticity Index	12.20%
Shell Husk	Water absorption	7.28%
	Specific Gravity	1.75
	Unit weight (g cm^{-3})	1.57

The Mactridae shell husk waste was collected from the seashore closed to Mie University, Tsu city, Mie Prefecture, Japan. A picture of the shell husk stockpile is shown in Figure 3. The shell husks were graded by performing sieve analysis. The fineness modulus and the maximum size of the abandon shell husks were 4.35 and 4.76 mm, respectively. The shell size distribution curve is shown in Figure 2 and its physical properties are given in Table 1. The engineering properties of soils can be increased by using any kind of cement. Ordinary Portland cement (Type I), which is commonly used and easy to find in local markets, was used in this study. The properties of this cement can be found in Hossain and Sakai (2008). Soil-shell husk-cement mixtures were mixed homogenously in the bowl with water added gently to dry mix. The average water content is 9%-12% which is on the dry side of optimum water content. Each sample was cured for seven days in room temperature.

Figure 3 Stockpile of shell husk waste, Tsu city, Japan

In this study, a total of thirty specimens are tested using CBR, DST and UCS. Sandy soil with 10% and 20% shell husk are combined with 2%, 4% and 6% cement respectively. A brief description of each testing method is given below.

2.1 California Bearing Ratio (CBR)

The ratio between resistance against the sinking of penetration piston into the soil with 1.27 mm min^{-1} (0.05 min^{-1}) velocity is defined as CBR. The resistance is shown by a standard crushed rock sample at each depth of penetration. Mostly, the CBR values are used in mechanistic design and as indicator of strength and bearing capacity of subgrade soil, subbase and base course material for pavement and foundation design (Yildgrim and Guynadin, 2011; Hazirbaba and Gullu, 2010). CBR test is economic and simple in comparison to other tests such as triaxial, simple shear and direct shear tests. The way CBR test is conducted can be adjusted and simulated based on the specific conditions needed. In previous studies, the CBR test was used to evaluate the reinforcing soil with various recycle aggregate and cement percentages (Choudhary et al., 2010; Basha et al., 2005).

After the mold had been assembled with bottom plate, spacer disc and mold extension, the soil samples were poured into it. The soil mixture was divided into three layers then tamped 67 times per layer with the 4.5 kg rammer. Then inside the layers were built subgrade layers which contain of soil, shell husk (10% and 20%) and cement (2%, 4% and 6%). The subgrade layer positions were shown in Figure 4 which was flattened using small rammer on the surface of each layer, and the height was 1 cm. The height of subgrade layers is based on ratio between field application and the laboratory scale is 1:5. After the sample had set up into the mold, it was kept inside the plastic bag to maintain the moisture content for 7 days. On the seventh day, the sample was taken out from the plastic then measured by using CBR testing machine. By using this machine, the loads were recorded for up to 12.5 mm of penetration. All CBR tests were carried out according to Japanese Industrial Standards (JIS-A-1211).

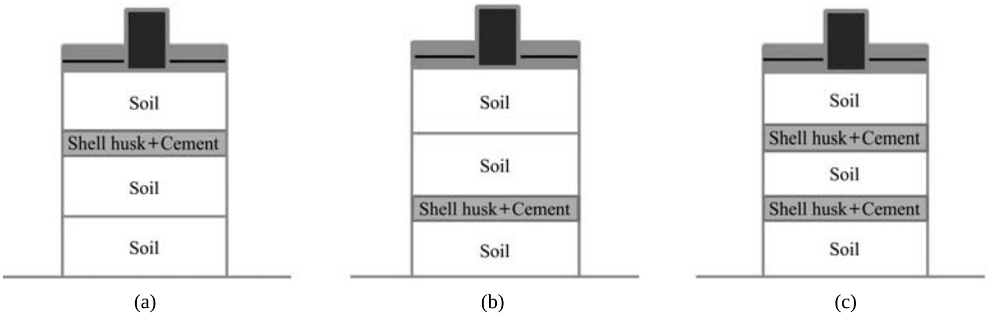

Figure 4 Soil-shell husk-cement layer (a) Upper layer, (b) Bottom layer, (c) Double layer, all layers containing shell-husk 10%, 20%, 30% and cement 2%, 4% and 6%

2.2 Direct Shear Test (DST)

The mixtures of shell, soil and water were filled in shear box in three layers. Each layer had the same compaction energy hence the density of soil-shell mixture was kept almost constant in every test. After completion of the compaction, the test specimens were cured for one week for strength development. Furthermore, the normal stresses (40, 60 and 80 kPa) respectively were applied to every specimen. The shear box was covered with plastic bag to avoid changing of water content ratio. After one week of curing, the shear load through screw jack was applied under electrically operated system with a constant speed of 1.0 mm min^{-1} and the force was measured using a tension load cell. Normal stresses (vertical load) are maintained stable during the curing period. The specification of this equipment is based on Japanese Geotechnical Society (JGS: T941-199X).

2.3 Unconfined Compressive Strength (UCS)

The specimens were manually compacted inside the mold with 12.5 cm in height and 5.0cm in diameter. The mixtures of soil-shell husk-cement were compacted in three layers using 4.9 cm diameter hand-rammer with rammer mass 1.0 kg and falling height of 30 cm. Each layer was compacted by 20 blows. The samples were tested using UCS at a loading rate of 0.1 mm min^{-1} and recorded every 0.5 mm displacement. These tests were carried out according to Japanese Industrial Standards (JIS-A-1211, 1980).

3 Results and discussion

Based on the methods proposed above, experimental results obtained from CBR, DST and UCS tests are presented and discussions made with respect to them in the following sections.

3.1 Results of CBR tests

Analysis in this part included the effect of shell husks percentages, subgrade layer types, and cement percentages. Figure 5 shows that by increasing the shell husk percentage, the CBR value of samples is increased. Samples with 20% shell husk percentage have the highest CBR values. Based on the assumption of interlocking particle between shell husk and soil, 20% shell husks are better distributed when it is compared with 10% shell husk. This gives more resistance to soil layer. Evaluation of the CBR values based on the subgrade type layers showed the variation values. It can be seen from Figure 5 that CBR values between subgrade double and upper layer on soil with 20% shell husk (cement 6%) and 20% (cement 4%) are slightly different. From Figure 6 could be seen that upper layer and double layer are closer to the surface of sinking, indicating more resistance in comparison to bottom layer. Even though double layer gives the highest value, upper layers are more effective for field application due to materials supplied and economic reasons. It has benefit on budgeting aspect for design and construction when using this combination.

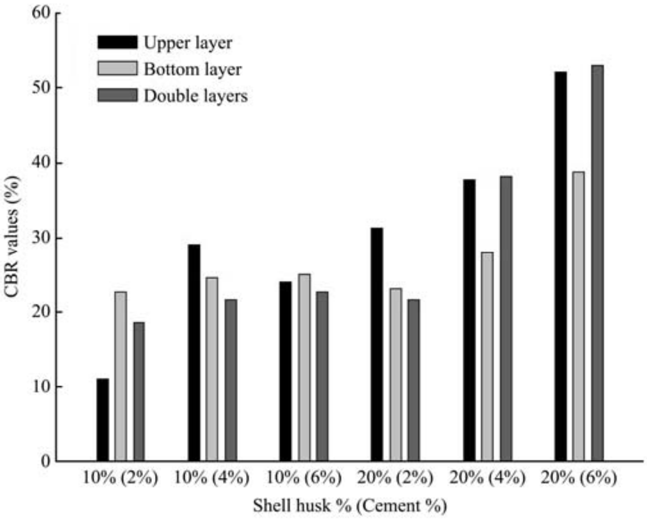

Figure 5 CBR value soil-shell husk-cement combination

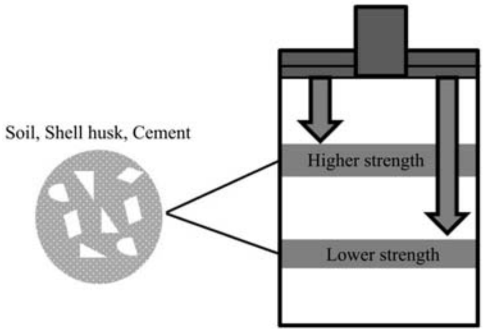

Figure 6 Mechanism strength of soil-shell husk-cement on CBR test

The figure also shows that the percentage of cement used does have significant effect to CBR values. Hossain and Sakai (2008) used SEM (Scanning Electron Micrographs) to explain the flocculation of soil particles where clay particles are brought together by cementing them to form a compound or secondary particle. This secondary particle is particularly responsible to strength development in cement treated soil even at nominal dosage rate of cement content. In summary, CBR of soils with 10% shell husk (cement 2%) for all type subgrade layers have lower values compare to others combination. On the other hand, combinations of soil with 20% shell husk (cement 6%) have higher CBR values for all subgrade layer type.

3.2 Result of DST

The relationship between maximum shear stress (τ) and normal stress (σ) of the soil-shell husk-cement are presented in Figure 7 and 8. It can be observed from Figure 7 that soils with 10% shell husk and 4% cement have the highest maximum shear stress and from Figure 8 that the soils with 20% shell husk and 6% cement have the highest maximum shear stress in comparison to the other scenario. It is then followed by soils with 20% shell husk and 4% cement. Soil with other percentages of shell husk and cement additions are not considered as a useful alternative.

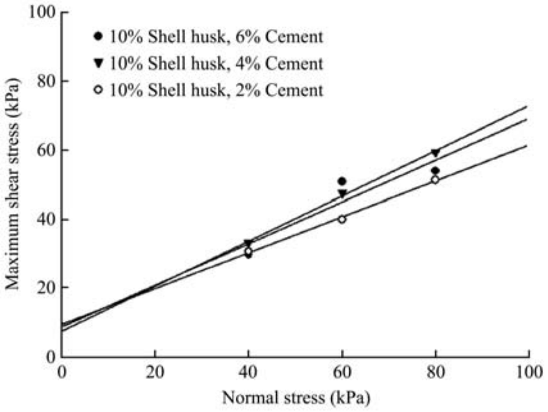

Figure 7 Normal stress vs maximum shear stress soil-shell husk-cement of 10% shell husk

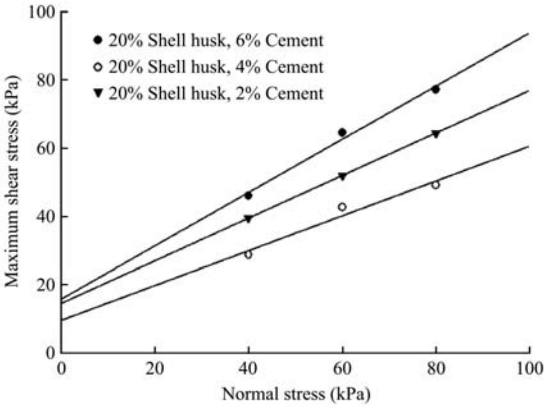

Figure 8 Normal stress vs shear strength soil-shell husk-cement of 20% shell husk

The shear strength of soils is the most important factor to investigate due to its main contribution to the stability of soil under the load (Hossain et al., 2006). Soil cohesion and internal friction are two factors that explained the soil shear strength as expressed in the Mohr-Coulomb failure criterion:

$$\tau_f = c + \sigma_n \tan \phi \quad (1)$$

where, τ_f (kPa) is the soil shear stress at failure; c (kPa) is the cohesion; σ_n (kPa) is the normal stress to the failure plane and ϕ (^{o}) is the internal friction angle (Mouazen et al., 2002). Figure 9 illustrates the mechanism on a direct shear test where shell husk particle and cement particle resist shear force throughout horizontal shear plane.

Both cohesion (c) and internal friction (ϕ) of soil-shell husk with cement addition are presented in Table 2. Cohesion of both soils with 10% and 20% shell husk increases linearly as cement percentage is increased. This is due to cementitious hydration as shown in Figure 10. This process forms a network and serves as the glue that provides strong structure and finally stabilized the soil (Prusinski and Bhattachaja, 1998). Note that the internal friction angle of soil with 20% shell husk also increases as the cement percentage increases. For the internal friction of soil with 10% shell husk, it increases up to 4% cement and then decrease at 6% cement. Similar observation of results was also found in Hossain et al. (2006).

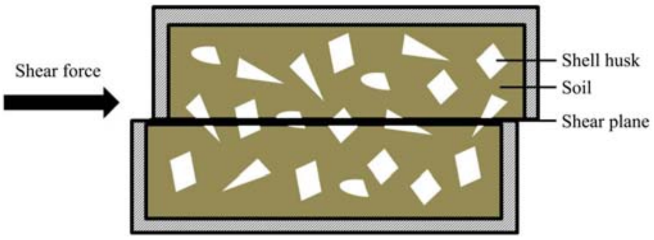

Figure 9 Shearing process of soil-shell husk-cement on direct shear test

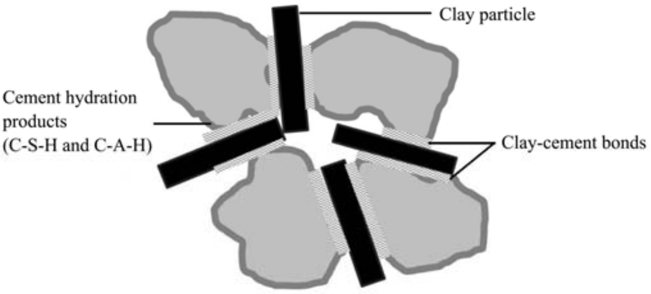

Figure 10 Hydration process

Table 2 Cohesion and internal friction angle of soil-shell husk-cement

Cement	Shell Husk 10%		Shell Husk 20%	
	Cohesion (c)	Internal friction (φ)	Cohesion (c)	Internal friction (φ)
2%	8.72	27.46	9.53	26.98
4%	8.9	32.4	14.62	31.88
6%	10.01	31.22	15.71	37.97

3.3 Result of UCStests

The UCS test is one laboratory test for pavement and soil stabilization application. It is also used as an index to evaluate soil improvement after treatment (Sariosseiri and Muhunthan, 2009). Figures 11 and 12 present the stress-strain relationship of six compositions of soils, shell husk and cement. Initially the compression curves of the specimens are slightly different and increment varies depending on the shell husk and cement percentage. Each curve shows the peak compressive stress at failure, and it then gradually decreases whilst showing the softening behavior. It is observed that soil with 20% shell husk has larger compressive strength than soil with 10% shell husk at same percentage of cement. As cement percentage increases so as the compressive strength of soil with shell husk.

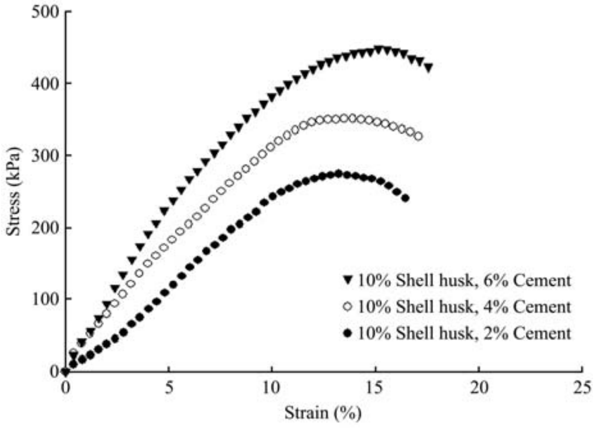

Figure 11 Stress-strain relationship of soil-shell husk-cement under compression with 10% shell husk

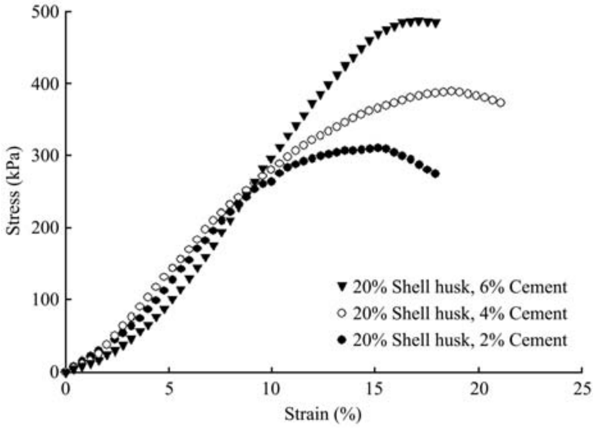

Figure 12 Stress-strain relationship of soil-shell husk-cement under compression with 20% shell husk.

Figure 13 presents the failure modes of a control sample and a soil-shell husk-cement sample. The control has major diagonal failure pattern whereas soil with cement and shell husk addition has various slip lines showing the potential discontinuity due to the addition. It is known that both shell husk and cement particle would have altered the failure modes of soil.

Figure 13 Failure mode of control sample (left) and soil-shell husk-cement (right)

Table 3 presents the moduli of elasticity (E_{50}) that was obtained using Equation (2).

$$E_{50} = \frac{q_u / 2}{\varepsilon_{50}} \tag{2}$$

In this equation, the 50% compressive strength is $q_u/2$ and ε_{50} is the compressive strain when $\sigma = q_u/2$ in kPa. Note from the table that very little variation on the modulus of elasticity for all six cases were found. This contrasts with the previous study by Hossain and Sakai (2008) which showed that, by using minimal dosage (<1%) of cement, both compressive strength and modulus of elasticity of clay soil are increased as the cement percentage increases. The main reason for this discrepancy is because of the soil-shell husk material used in this study. It can therefore be concluded that no direct benefit on the modulus of elasticity with the addition of cement to the current soil-shell husk material.

Table 3 Compressive strength and modulus elasticity of soil-shell husk-cement

Composition	Compressive strength (kPa)	Modulus of elasticity (MPa)
Shell Husk 10%, Cement 2%	273	2.36
Shell Husk 20%, Cement 2%	309	2.57
Shell Husk 10%, Cement 4%	350	3.58
Shell Husk 20%, Cement 4%	389	2.99
Shell Husk 10%, Cement 6%	447	2.34
Shell Husk 20%, Cement 6%	487	2.83

4 Conclusion

Based on the study in the paper, the following conclusions are drawn:

1. The addition of shell husk and cement increased the CBR value of all types of subbase layers. The highest CBR value was achieved by 20% shell husk with 6% cement. For practical and economic reasons, it is recommended to use the upper layer case in agriculture application.

2. The direct shear test showed that by increasing the shell husk-cement percentage the shear strength of soil also increased. The largest cohesion and internal friction angle were achieved for the 20% shell husk with 6% cement.

3. The increase of shell husk and cement percentage increased the compressive strength of the soil. There was very little variation in the estimation of the moduli deformation for all study.

The utilization of shell husk waste and cement as a ground improvement material are to be encouraged in agriculture land development.

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