# Shear strength of soil by using clam shell waste as recycle aggregate

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## Abstract

Every year in Japan, industry and household consumption generate a significant amount of clam shell waste. It has inevitably imposed a negative impact on the national environment and economics. To reduce those effects, this study proposes the reutilisation of abandoned clam shell for ground improvement. An experimental study was conducted to evaluate the shear strength of this new construction material. Soils were mixed with various percentages of clam shells as well as cement. The new soil-clam shell-cement samples were tested under the triaxial consolidated-drained tests (CD tests). Test results showed that the addition of clam shell and cement in the soil leads to increase deviatoric stress. Furthermore, shear strength parameters of specimens were quantified in terms of cohesion and frictional resistance. Based on the results of the current study, it was concluded that approximately 9.50% increase of frictional angle can be achieved whilst the cohesion can only be improved by 6%. This new construction material can be used in the future for the base course of unpaved roads in agriculture engineering applications.

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Key words: Clam shell waste; cement; ground improvement; principal stress difference; axial strain; shear strength.

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## Introduction

Annually, enormous volume seashell-by-products (SBP) are produced in all over the world. Burning and burying are the most common way to treat those kinds of waste (Motamedi *et al*., 2015). All those disposal processes affect a severe problem of environment and economic perspective. An example of SBP in Japan is abandoned clam shell by total amount 151,000 tons/year which take nearly 32 million US$ is spent on disposal (Hossain, 2013). That budget is undesirable despite Japan being a developed country. While in developing countries, many illegal dumping occurs due to the high cost of disposal waste. Most of the clam shell is usually disposed of in landfills (Figure 1A). In a long time, if this waste is not treated properly, it could cause air pollution and other environmental problems. These circumstances motivate the development of technologies using an abandoned clam shell (Motamedi *et al*., 2015; Yoon *et al*., 2009).

The utilisation of abandoned clam shell is expected to solve the main problems in environmental and economic aspects, such as: i) waste storage problem; and ii) protection of limited natural resources of aggregates (Hossain, 2013). From the point of view the potency of clam shell, it is composed mainly of 95-99% (by weight) of $CaCO_3$ that is potentially converted into CaO for reinforcing the soil or binding the material (Motamedi *et al*., 2015; Park *et al*., 2014). In the previous study, the clam shell was used as a recycling aggregate for ground improvement. By using the direct shear test, the result showed that a certain amount of clam shell increased the shear strength of soil (Rachmawati and Zakaria, 2017).

In this study, the abandoned clam shell was used as the recycle aggregate for ground improvement. Ground improvement techniques are provided to increase the soil strength, to reduce compressibility, and to enhance the performance under the load. The triaxial tests are performed to evaluate the shear strength of specimens that contained soil (only), soil-clam shell, soil-cement, and soil-cement-clam shell. The utilisation of cement was applied because an additional 4 to 14% of cement could improve the properties of soil (Hossain and Sakai, 2008). Furthermore, the addition of cement can be used for modified and stabilised purposes. Modified means to improve workability and compaction characteristics while the term stabilised is encouraging to improve the mechanical behaviour of cement-treated soil (Sarriosseiri and Muhunthan, 2009). In this study, all specimens are evaluated by the triaxial test. It is the most reliable method for determining shear strength parameters under different drainage conditions (Arora, 1978). The triaxial test provides information on the stress-strain behaviour of the soil that the direct shear test does not. It also provides a more uniform stress condition than the direct shear test with its stress concentration along the failure plane (Das, 2007).

## Materials and methods

Soil, clam shell, and cement are used as materials of the specimen in this research. The soil sample was taken nearby the Shiratsuka Port in Mie Prefecture Japan. Based on the results of laboratory testing using the Unified Classification System, sand was the highest part of this soil with silt and clay as another part. Both of the properties of soil and clam shell waste are given in Table 1.

Clam shell waste was collected from the seaside which to Mie University, Tsu City, Mie Prefecture, Japan. Surf clam (Mactridae) was the source of clam shell which had been used in this research. The shell of surf clam was quite strongly constructed due to its habit which likes to burrow in rocks. It is well known that surf or trough clam has a smooth surface, with concentric growth lines and covered by thin periostracum (Vaughan, 2001). The results of the sieving analysis showed that the fineness modulus and the maximum size of the abandoned clam shell were 4.35 and 4.76 mm, respectively. The soil and shell size distribution curves are presented in Figure 1B. From a total of 16 specimens, 12 specimens contained cement percentage. The type of cement is Ordinary Portland cement (Type I), which was commonly used and easy to find in local markets. The properties of this cement can be found elsewhere (Hossain and Sakai, 2008).

All the test specimens were manually compacted inside the mold with 12.5 cm in height and 5.0 cm in diameter. The specimens were control (soil only), soil-cement percentages (2%, 4%, 6%), soil-clam shell percentages (10%, 20%, 30%), and combination of the soil-cement-clam shell by using both similar percentages previously mentioned. Further, the soil was mixed with separated clam shell and cement percentages or both materials depending on the composition. The specimens were compacted in three layers using a 4.9 cm diameter hand-rammer with rammer mass of 1.0 kg and a falling height of 30 cm. Each layer was compacted by 20 blows. The average water contents were 9%-12% which observed on the dry side of optimum water content. Specimens which contained cement were cured for seven days at room temperature. After that, consolidated-drain (CD) test triaxial compression tests were conducted to evaluate specimens.

### Testing method

The specimens are evaluated using trixial apparatus as shown in Figure 1C. Initially, the triaxial chamber was assembled from

**Table 1. Properties of soil and clam shell.**

| Particles | Parameters | Values |
|---|---|---|
| Soil particle | Dry density ($\rho_d$) | 1.76g/cm$^3$ |
| | Optimum Water Content ($W_{opt}$) | 13.29% |
| | Specific gravity ($\rho_s$) | 2.589 |
| | Cohesion ($c$) | 60.95 |
| | Angle of internal friction ($\varphi$) | 32.75 |
| | Sand >75 μm | 55.56% |
| | Silt >5-75 μm | 24.64% |
| | Clay <5 μm | 19.80% |
| | Liquid limit | 41.00% |
| | Plastic limit | 34.72% |
| | Plasticity Index | 6.28% |
| Clam shell | Water absorption | 7.28% |
| | Specific Gravity | 1.75 |
| | Unit Weight (g/cm$^3$) | 1.57 |



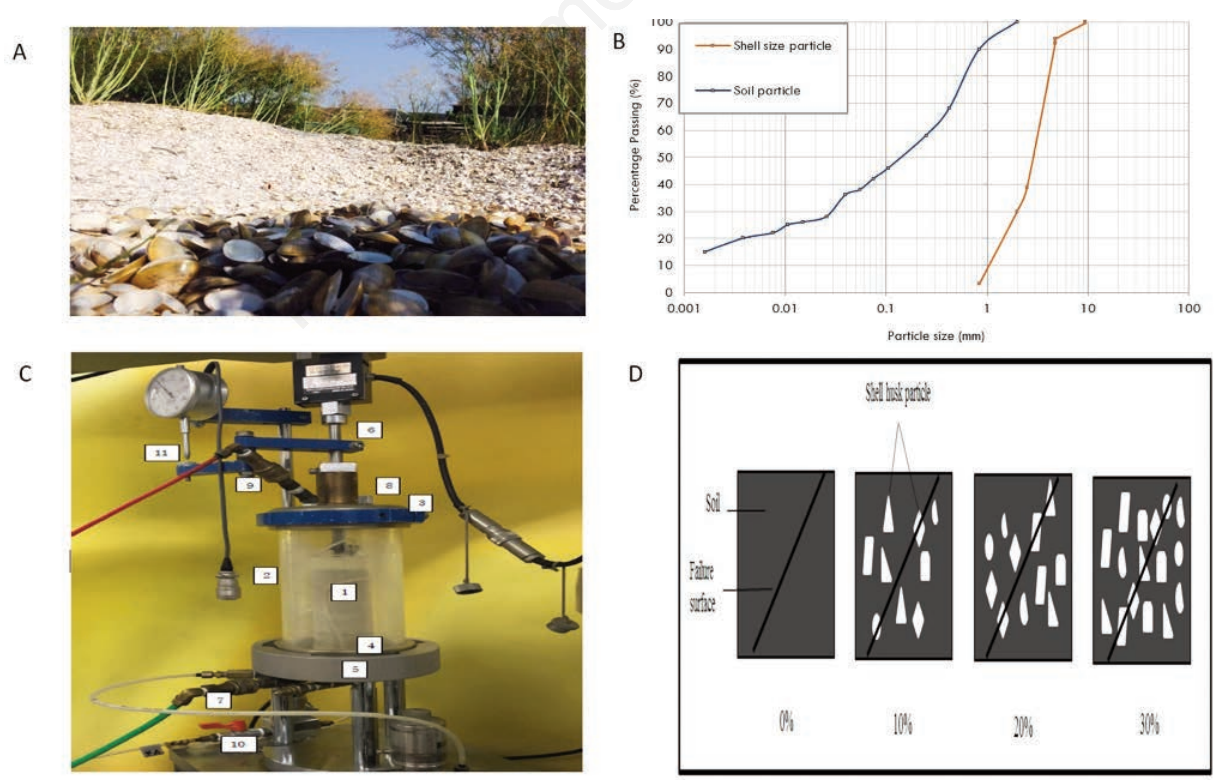


**Figure 1. A) Clam shell waste; B) Particle size distribution curve; C) Triaxial apparatus; D) Failure surface of specimen soil-clam shell.**

the soil specimen sealed by the rubber membrane (1). After that, in the baseplate groove (4), the chamber cylinder was installed (2), and then, the top plate was positioned on it (3). The three components of the triaxial chamber (*i.e*., baseplate, chamber cylinder, and top plate) were clamped together by tightening the tie ring (5). The specimen cap has a circular indentation at the centre, and the position of loading piston (6) should be aligned. It was achieved by pushing down the loading piston and verified precisely into the centre of the specimen cap. Next, the chamber was filled with the fluid from the water channel (7), and at the same time, air releases valve on top cap kept open (8). Axial stress (σ) was applied through the loading piston and during the process, the dial gauge (11) connected with piston and specimen recording vertical deformation. The hydrostatic chamber pressure was implemented using the air channel (9) on the top cap while the air release valve on top cap closed. The confining pressures in this research were 50 kPa, 100 kPa, 150 kPa, 200 kPa. During the test, the water valve (10) was kept open due to drained condition requirements in CD test. When the ultimate value of the principal stress difference ($\sigma_a$-$\sigma_r$) was reached, then the test will be stopped. However, if an ultimate value was not recorded, then the peak value of the principal stress difference ($\sigma_a$-$\sigma_r$) defined at 15% axial strain (JGS 2001).

## Results and discussion

### The relationship between differential stress ($\sigma_a$-$\sigma_r$) and axial strain ($\varepsilon_a$)

Figure 2 shows the relationship between axial strain ($\varepsilon_a$) and principal stress difference ($\sigma_a$-$\sigma_r$) of soil composite with 0%, 10%, 20%, and 30% clam shell is illustrated. Most specimens under confining pressure 50 kPa and 100 kPa showed the ultimate principal stress differences ($\sigma_a$-$\sigma_r$) then followed by softening behaviour (Figure 2A-2D). On the other hand, under confining pressures of 150 kPa and 200 kPa, the ultimate principal stresses for other specimens were defined on 15% axial strain because the peak value had not achieved. However, soil with clam shell 30% (Figure 2D) reached the highest principal stress difference ($\sigma_a$-$\sigma_r$) under confining pressure 200 kPa, followed by softening behaviour shown by the peak value of axial strain (less than 15% axial strain).

The relationship between axial strain ($\varepsilon_a$) and principal stress difference ($\sigma_a$-$\sigma_r$) of the specimen which treated by 2%, 4%, and 6% cement addition was given in Figure 3. The graphs show cement addition led to a decrease in the axial strain of the specimen. The increasing of cement percentage developed the



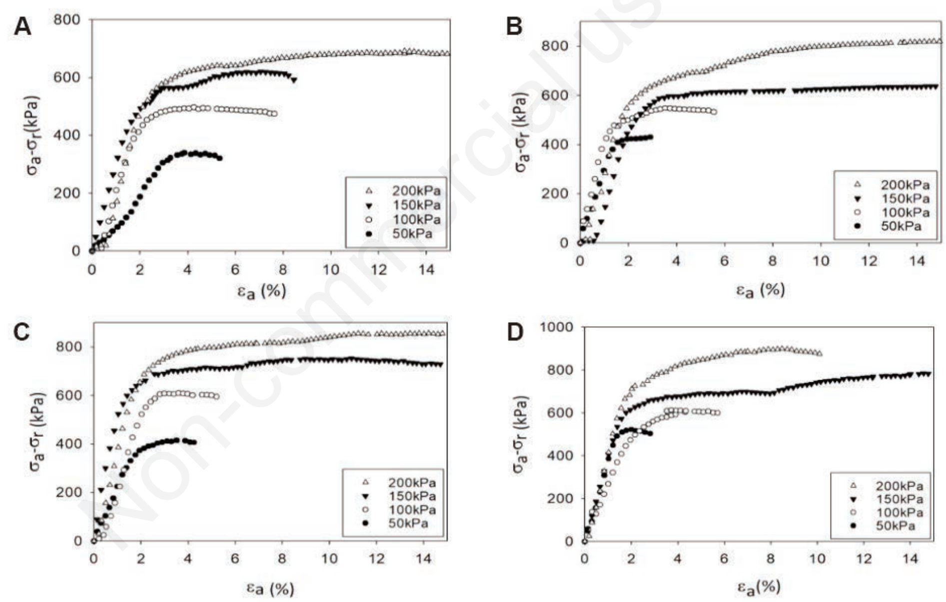


**Figure 2. The relationship between axial strain (Ɛa) and principal stress difference (σa-σr) of soil composite with 0% (A), 10% (B), 20%(C) and 30%(D) clam shell.**

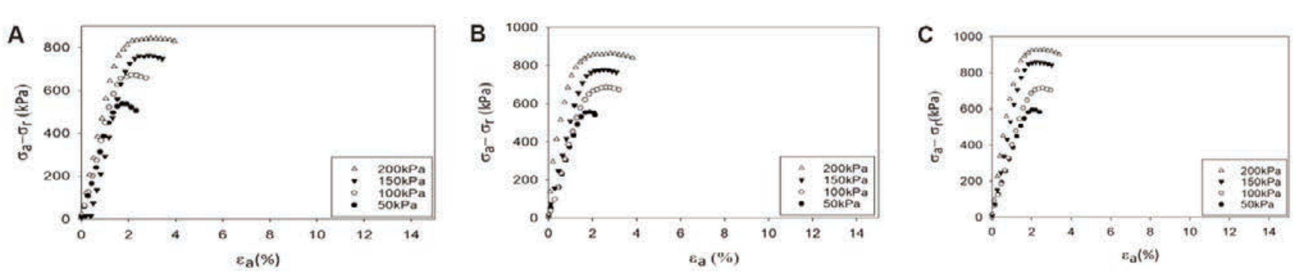


**Figure 3. The relationship between axial strain (Ɛa) and principal stress difference (σa-σr) of specimen which treated by 2%(A), 4%(B) and 6%(C) cement addition.**

principal stress difference ($\sigma_a$-$\sigma_r$) of specimens and the highest principal stress difference ($\sigma_a$-$\sigma_r$) had reached by the addition of 4% cement. Most of the maximal principal stress differences ($\sigma_a$-$\sigma_r$) were defined at 4% axial strain ($\varepsilon_a$) (Figure 3A-3C). Furthermore, the specimens were treated by a combination of cement and clam shell (Figure 4-6), the graphs show typically the combination of clam shell-cement increasing the axial strain ($\varepsilon_a$), compared to the specimen using only cement (Figure 3).

It was observed that overall specimen behaviour was significantly affected by the addition of clam shell and cement percentage. Illustration of the relationship between axial strain ($\varepsilon_a$) and principal stress difference ($\sigma_a$-$\sigma_r$) of all specimens showed that peak strength and brittleness behaviour changed due to separated or combined effects of clam shell and cement percentages. From this figure, it was known that increasing confining pressure enhances the principal stress differences ($\sigma_a$-$\sigma_r$). Most of the soil-clam shell specimens showed the ultimate principal stress differences ($\sigma_a$-$\sigma_r$) which defined on 15% axial strain. On the other hand, soil with cement addition showed peak strength and then decreased the axial strain. It was recognised that soil treated by cement exhibited much more stiffness and brittle behaviour than non-treated soil (Consoli *et al.*, 1998; Sariosseiri and Muhunthan, 2009). Figure 7 presents failure pattern after triaxial test for (A) control, (B) soil-clam shell, (C) soil-cement, (D) soil-cement-clam shell respectively. As can be seen, the failure patterns (C) and (D) show cracking which means brittle behaviour due to cement addition.

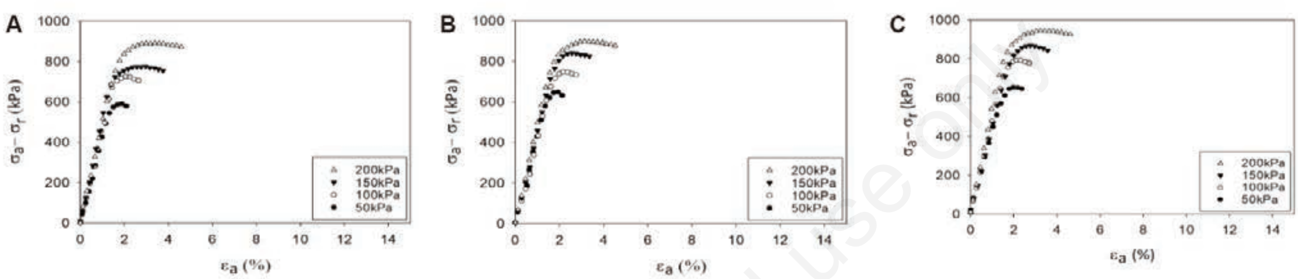


**Figure 4. The relationship between axial strain (Ɛa) and principal stress difference (σa-σr) of specimen which treated by combination of cement addition and clam shell; 2% cement and 10% clam shell (A), 4% cement and 10% clam shell (B) and 6% cement and 10% clam shell (C).**

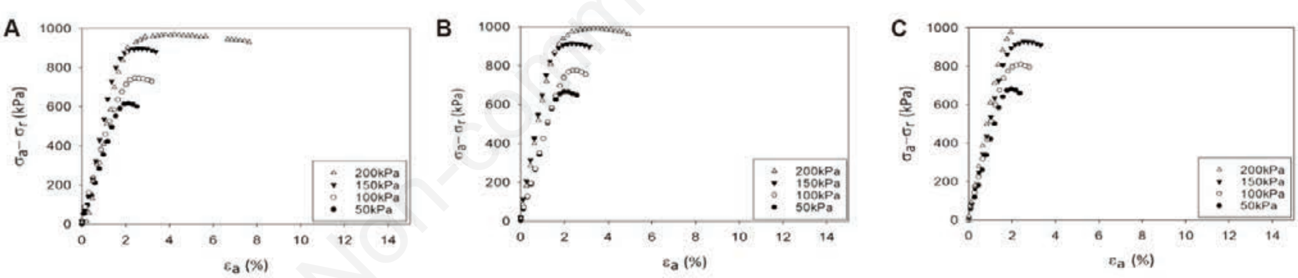


**Figure 5. The relationship between axial strain (Ɛa) and principal stress difference (σa-σr) of specimen which treated by combination of cement addition and clam shell; 2% cement and 20% clam shell (A), 4% cement and 20% clam shell (B) and 6% cement and 20% clam shell (C).**

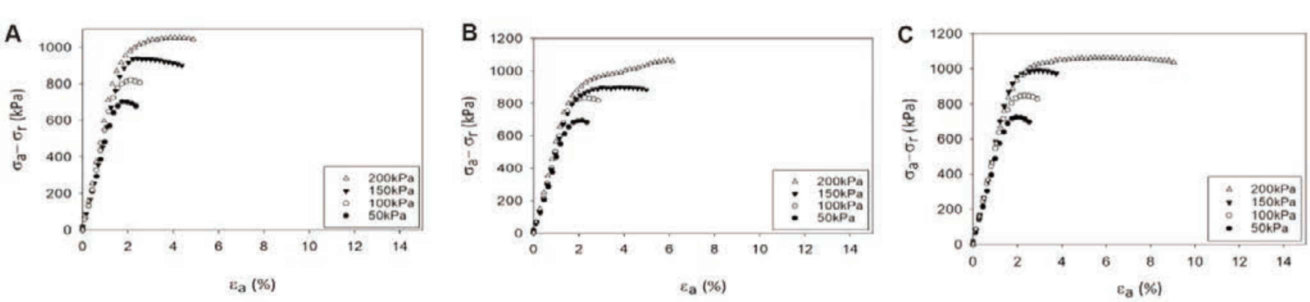


**Figure 6. The relationship between axial strain (Ɛa) and principal stress difference (σa-σr) of specimen which treated by combination of cement addition and clam shell; 2% cement and 30% clam shell (A), 4% cement and 30% clam shell (B) and 6% cement and 30% clam shell (C).**

### Shear strength of soil composition with clam shell percentages

The triaxial test had a failure surface that reflected the real stress-strain characteristic of samples compared to the direct shear test. In the triaxial test, several different conditions *i.e.* drained, undrained, consolidated, and unconsolidated can be simulated. The triaxial compression test had chosen as an accurate and reliable method by many researchers (Zhang *et al*., 2010). The calculations were obtained by Mohr-Coulomb criterion as a linear function of the normal stress ($\sigma_f$) on the plane at the same point which followed by the equation (Mouazen *et al*., 2002):

$$\tau_f = c + \sigma_f \tan \varphi \quad (1)$$

An angle of internal friction (φ) was the measure of the shear strength of soils due to friction of soil and reinforcing materials (Zhang *et al*., 2010). On the other hand, cohesion (c) held the particles of the soil together in a soil mass and independent of the normal stress (Arora 1978). Table 2 results are calculated by using equation 2 to obtain (c) and (φ):

$$\sigma_a = \sigma_r \tan^2 (45 + \varphi/2) + 2c \tan (45 + \varphi/2) \quad (2)$$

The calculation was referred to equation 1, where $\sigma_a$ and $\sigma_r$ were the major and minor effective principal stresses, respectively (Das, 2007).

Indexes of shear strength, the angle of internal friction (φ) and cohesion (c) of specimens are summarised in Table 3. This table shows that clam shell addition enhanced the angle of internal friction of soil-clam shell composite. It was attributed to the irregular shape of clam shell particle which developed the frictional resistance between particles. For the specimen soil-cement-clam shell, the increase in clam shell percentage also increased the angle of internal friction. However, soil with cement addition had a lower angle of internal friction compared to control and soil with clam shell only. It may due to anti-synergetic action between the angle of internal friction and cohesion because specimens with cement addition had higher cohesion than other specimens (Hossain *et al*., 2006).

The enhancement of cohesion was also known as the primary function of the cementation process due to cementitious hydration. Clam shell also had an essential role to increase the cohesion of specimens up to 20% clam shell. Clam shell had $Ca^{2+}$ which attracted negative ion of soil which caused interlocking mechanism between soil and clam shell particles. However, the cohesion was reduced at 30% clam shell for both specimen soil-clam shell and soil-cement-clam shell. It was realised that the high percentages (>20%) of clam shell also increased brittle behaviour which had a consequence for the angle of internal friction and cohesion of specimen. The decreasing of soil cohesion after 20% clam shell addition occurred in previous research which observed the shear

**Table 2. Ultimate principal differential stress ($\sigma_a$-$\sigma_r$) of samples.**

| Samples | Confining pressure (kPa) 50 | 100 | 150 | 200 |
|---|---|---|---|---|
| 0% Shell husk | 389.5 | 560.2 | 769.8 | 891.3 |
| 10% Shell husk | 480.3 | 647.9 | 787.3 | 1019.3 |
| 20% Shell husk | 464.7 | 709.5 | 902.2 | 1055.8 |
| 30% Shell husk | 572.8 | 713.5 | 934.9 | 1099.6 |
| Cement 2% | 588.6 | 771.7 | 912.7 | 1043.4 |
| Cement 4% | 607.2 | 787.6 | 929 | 1063.7 |
| Cement 6% | 645 | 816 | 1009.4 | 1127.9 |
| 10% Shell husk (2% Cement) | 641 | 825.3 | 926.1 | 1092 |
| 10% Shell husk (4% Cement) | 698.7 | 848.6 | 991.8 | 1099.1 |
| 10% Shell husk (6% Cement) | 703.3 | 892.4 | 1018.9 | 1145.8 |
| 20% Shell husk (2% Cement) | 668.5 | 846.7 | 1049.5 | 1169.3 |
| 20% Shell husk (4% Cement) | 717.8 | 875.9 | 1066.2 | 1192.7 |
| 20% Shell husk (6% Cement) | 732.4 | 909.5 | 1078.7 | 1245 |
| 30% Shell husk (2% Cement) | 753.3 | 921.4 | 1089.5 | 1253 |
| 30% Shell husk (4% Cement) | 745.6 | 934.7 | 1051.9 | 1267 |
| 30% Shell husk (6% Cement) | 776.1 | 948.7 | 1141.8 | 1264.3 |



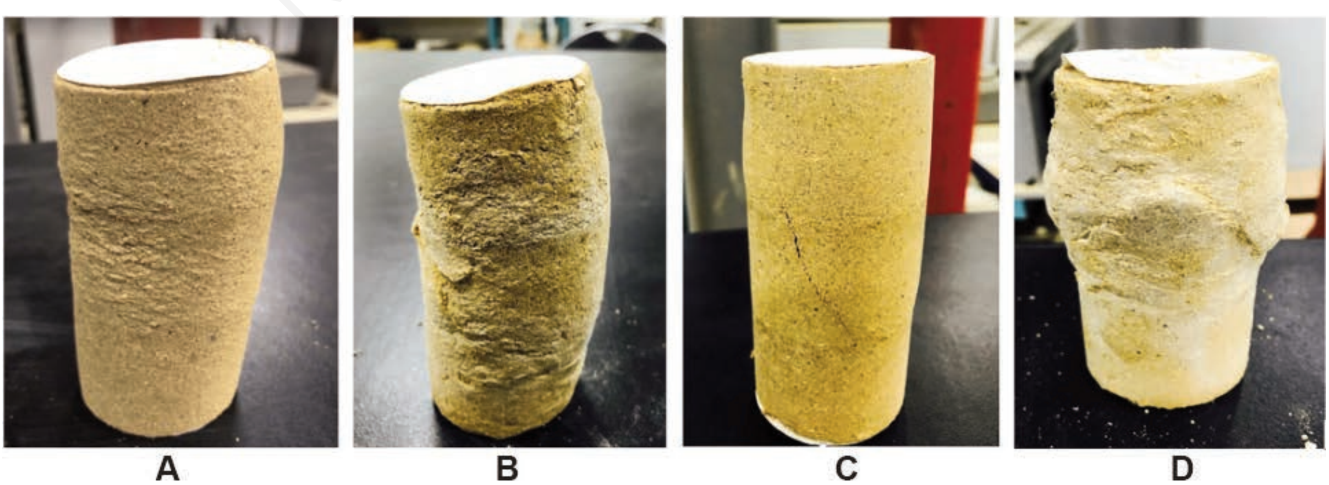


**Figure 7. Failure pattern of samples. A) control; B) soil-clam shell; C) soil-cement; D) soil-cement-clam shell.**

strength of soil with clam shell reinforcement using a direct shear test (Rachmawati and Zakaria, 2017).

Calculation of shear strength based on the angle of internal friction and cohesion are also presented in Table 3. This table shows that clam shell percentage reinforced specimen. The reinforcement of clam shell percentage is illustrated in Figure 1D. It is explained that clam shell percentage enhanced shear strength of specimen by impeding failure surface. The results showed a specimen that had clam shell and cement percentage combination had higher shear strength than those specimens with cement addition only or clam shell addition only. Both angles of internal friction and cohesion may increase or decrease by clam shell and cement percentage addition, but generally, the final results were an increase in shear strength.

## Conclusions

The effects of clam shell and cement addition into natural soils were investigated in this paper. A total of sixteen samples had been examined using the triaxial tests and the results reported concerning its principal differential stress ($\sigma_a$-$\sigma_r$), axial strain ($\varepsilon_a$) internal friction (φ), cohesion (c) and shear strengths ($\tau_f$). In general, the angle of internal friction increases with the increase in clam shell percentage. This is due to the nature of the various shapes of clam shell, which contribute to the friction and interlocking between particles. Nevertheless, the increases in cohesion is not pronounced which can be expected from the increased discontinuity in this new material.

It can be concluded that clam shell contributes to the improvement of the angle of internal friction while cement improves cohesion. It is, therefore, promising to see the future use of this new construction material consisting of soil, clam shell, and cement in the application of agricultural road. It is recommended that future work should be give concern to Young's Modulus of this material.

**Table 3. The angle of internal friction and cohesion of specimens.**

| Samples | $\phi$ | $c$ |
|---|---|---|
| 0% Shell husk | 32.75 | 60.95 |
| 10% Shell husk | 33.53 | 76.91 |
| 20% Shell husk | 34.15 | 93.39 |
| 30% Shell husk | 35.90 | 89.14 |
| Cement 2% | 24.11 | 117.07 |
| Cement 4% | 24.30 | 119.79 |
| Cement 6% | 31.78 | 141.41 |
| 10% Shell husk (2% Cement) | 28.61 | 153.37 |
| 10% Shell husk (4% Cement) | 29.42 | 161.94 |
| 10% Shell husk (6% Cement) | 32.14 | 162.13 |
| 20% Shell husk (2% Cement) | 32.86 | 137.67 |
| 20% Shell husk (4% Cement) | 33.01 | 146.71 |
| 20% Shell husk (6% Cement) | 33.49 | 151.00 |
| 30% Shell husk (2% Cement) | 32.78 | 159.58 |
| 30% Shell husk (4% Cement) | 33.04 | 157.73 |
| 30% Shell husk (6% Cement) | 34.76 | 153.54 |



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