Applicability of Cement Treat Granulate Soil for Subgrade Material

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ABSTRACT: Cement-Treat Granular Soil (CTGS) is produced by mixing dredged clay with proper amount of cement and polymer. CTGS has beneficial uses of granular material and much higher strength and stiffness than those of original clay so that it been expected to apply for construction material. This study presents the mechanical characteristics of two types of CTGS produced from dredged marine clay mixing with low proportion of Portland cement and polymer. The applicability of the CTGS for the foundation structure of road is characterized through durability of CTGS particles against weathering, stiffness and shear strength based on results of compaction tests, California Bearing Ratio (CBR) tests and a series of CD triaxial tests. The test results indicate that CTGS has a relatively high porosity, high strength and good characteristics of granular material, such as ease of compaction, good drainage that are sufficient for subgrade soil.

KEY WORDS: Cement Treat Granulate Soil, Dredged Marine Clay, Durability, Compaction Test, CBR test, CD triaxial test, Subgrade material.

1 INTRODUCTION

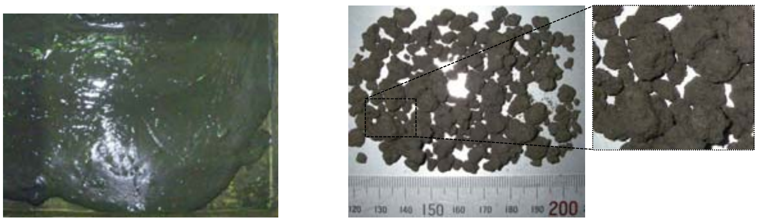
The utilization of dredging material at regional area for construction has been a challenge of civil engineers for economical and environmental purposes. In general, the waste soils with low strength and high water content are stabilized and solidified by mixing with additives (e.g., cement, lime), by which the mechanical properties, strength, compressibility and permeability are enhanced as solidification is achieved. The cement-soil or lime-soil has been extensively studied and practically used in many engineering projects as well as road construction projects as base, subbase and/or subgrade materials (Tatsuoka, et al., 1997; Coastal Development Ins. of Tech., 2003; Tsuchida and Egashira, 2004; Sungmin and Murad, 2009; etc), though these conventional methods still remain issues on cost, environment as well as engineering characteristics. In another context, the granular material so far has been considered as a valuable choice for the base or subgrade material by its beneficial uses, such as easy transportation, good drainage and ease of field compaction, etc. Thus, such treated granulate soils would have a high feasibility for construction.

As a new approach, CTGS, a granular material, is produced from dredged clay by mixing with appropriate amount of cement and polymer (Takahashi et al., 2009; Dong et al., 2009). CTGS has higher strength than untreated soil and high porosity that gives relatively lightweight material; therefore, it is expected to apply for subgrade soil. The applicability of

CTGS produced by lean-mixture design for subgrade material was featured out based on laboratory tests including durability tests, compaction test (JIS, 1999), CBR (JIS, 1998) test and CD triaxial compression test (JGS, 2000).

2 MATERIALS

In this study, dredged clay (Fig.1.a) from Kawasaki port of Japan was used to produce material. The some physical properties of this low workability and high water content clay are shown in Table 1. The normal Portland cement and the Aqupaana (partially neutralized polyacrylic acid) polymer manufactured by Sumitomo Seika Company were used to stabilize and solidify the clay. The clay was first stirred to be homogeneous slurry whilst its water content was adjusted to be 60% ($1.2w_L$), subsequently mixed with polymer in 2 minutes and followed by 5 minutes mixing with cement by a blade-mixing machine. After mixing thoroughly, CTGS (Fig.1.b) was then cured in trays, covered by plastic sheet to keep constant water content at room temperature during curing time. Since the effects of curing time on strength and stiffness of cement soil mixing have been well established, all material using in this study was cured for more than two months. The detailed mixing procedure can be seen in Takahashi et al. (2009) or Dong et al. (2009).



(a) (b)

Figure 1: (a) Kawasaki clay and (b) CTGS (C_1)

Table 1. Physical properties of Kawasaki Clay

Properties	Value
Plastic limit, w_P (%)	23.0
Liquid limit, w_L (%)	48.6
Specific density, ρ_s (g/cm^3)	2.68
Percentage of sand	14.0
Percentage of silt	42.0
Percentage of clay	44.0

Table 2. Physical properties of CTGS

Properties	C_1	C_2
Specific density ρ_s (g/cm^3)	2.79	2.68
Water content, w (%)	44.82	39.2
pH	10.64	11.34
d_{60} (mm)	4.98	3.4
d_{10} (mm)	1.56	1.2
Coefficient of uniformity U_c	3.14	2.83
Maximum void ratio, e_{max}	3.35	2.98
Minimum void ratio, e_{min}	2.44	2.23
Maximum dry density, ρ_{max} (g/cm^3)	0.811	0.834
Minimum dry density, ρ_{min} (g/cm^3)	0.641	0.677

We herein selected two mixture design of Portland cement and polymer to produce two types of CTGS, which have reasonable production costs and are named as following: (i) C_1 type: 5% cement, 0.1 % polymer to the wet weight of clay and corresponding to 45 kg/m^3 of cement, polymer of 0.89 kg/m^3 (ii) C_2 type: 15% cement, 0.3% polymer to the wet weight of clay, or cement of 124 kg/m^3, polymer of 2.5 kg/m^3. Recent works on cement treated soil has been demonstrated that the water/cement ratio is an important factor influencing on strength of treated clay (Horppibulsuk, 2003; Lorenzo and Bergado, 2004). These water/cement mixtures are ensured that there is sufficient water for full hydration and sufficient to characterize the strength and stiffness of cement treated clay. Some physical properties of the CTGS are shown in Table 2. Notably, the minimum void ratios and maximum dry density were evaluated by the vibration table tests in order to obtain maximum density of CTGS with minimum particle crushing.

3 EXPERIMENTS AND RESULT DISSCUSSIONS

3.1 Durability against the Weathering

The durability of CTGS particles against the weathering was investigated by cyclic wetting and drying test in the laboratory. Three samples for each type of material C_1 and C_2 were prepared in trays. In each cycle of wetting and drying, the material was soaked in de-aired water at the room temperature (about 24 C^o) for 24 hours then dried in an oven at 100 C^o for 24 hours and cooled down at the room temperature. After each cycle, the alternation of particles size was simply examined by sieve analysis. Figure 2 shows the grading curves of original Kawasaki clay, C_1, C_2 and those of C_1 and C_2 after 6 and 12 cycles. Based on ASTM soil classification, C_1 and C_2 are both classified into GP. A slight alteration of the grading curves reveals only a minor change of particles size until 12 cycles that indicates a high durability of CTGS against the cyclic wetting and drying conditions. This is an essential characteristic for subgrade material.

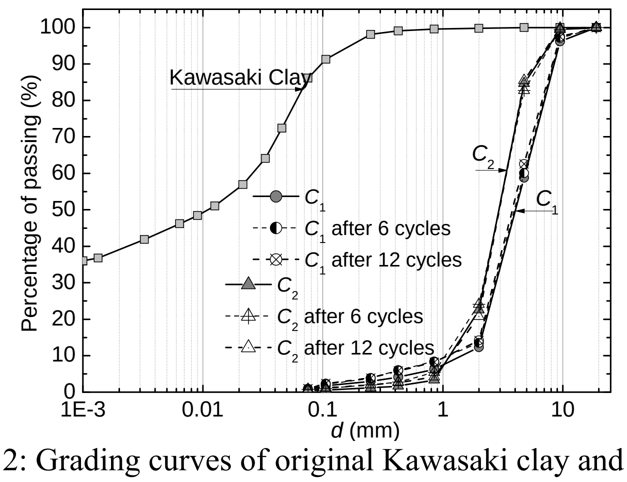


Figure 2: Grading curves of original Kawasaki clay and CTGS

3.2 Compaction Tests

The samples were prepared at the different water contents and compacted in a cylindrical mold with two levels of compaction energy. The detailed conditions of compaction tests are presented in Table 3.

It can be seen based on Table 3 that CTGS is a relatively light material because the dry density is quite small even in compacted specimens. The compaction curves of both C_1 and C_2 (Fig. 3) show that optimum water content of CTGS is not clearly observed. The compaction curves are quite gentle and reach to the air-zero curves as water content increases. This result differs from those obtained from some soils, especially clay or fine-particle granular material, where the compaction curve shows a yield bell-curve with the obvious optimum water content at which the soils can obtain a maximum dry density. This difference can be explained that CTGS has a high porosity so that air and pore-water can be easily expelled during compaction, and the CTGS particles can be moved and rearranged into denser configuration with lesser difficulty than that in cases of fine particles materials. In other word, water content is not strongly affected on the effective compaction. This could be seemed as a good characteristic of CTGS for field application because natural water content CTGS can be used for compaction at the site without water content adjustment.

In addition, the maximum dry densities of CTGS obtained by compaction tests are considerably larger than those evaluated by vibration test (Table 2) that indicates a significant particle crushing caused by compaction. Hence, the reduction in volume of material consists of the particles rearrangement, particles deformation and particles crushing. The larger compaction energy probably induces greater degree of particles crushing.

There seems be a difficulty to increase density of CTGS because the compaction energy increases about three times though the dry density is not significantly increased. It may depend on grain sizes distribution when C_1 and C_2 are both grouped into poor grade soil (ASTM); however, it is expected that the change in volume of CTGS could be dominantly induced by rearrangement of CTGS particles when compaction energy reaches to a certain level of compaction energy. Over this level, particles crushing and particle deformation significantly increase and contribute to the total change in volume of CTGS.

Table 3. Compaction test preparation

Weight of rammer (kg)	Falling height (cm)	N_{blows} /layer	Number of layers	E_c (kJ/m^3)
2.5	30	25	3	552
4.5	45	25	5	1807

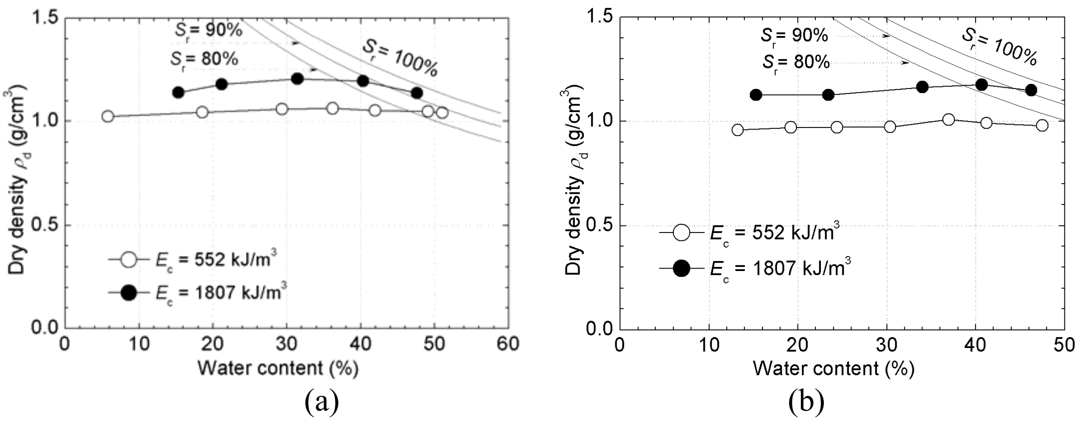


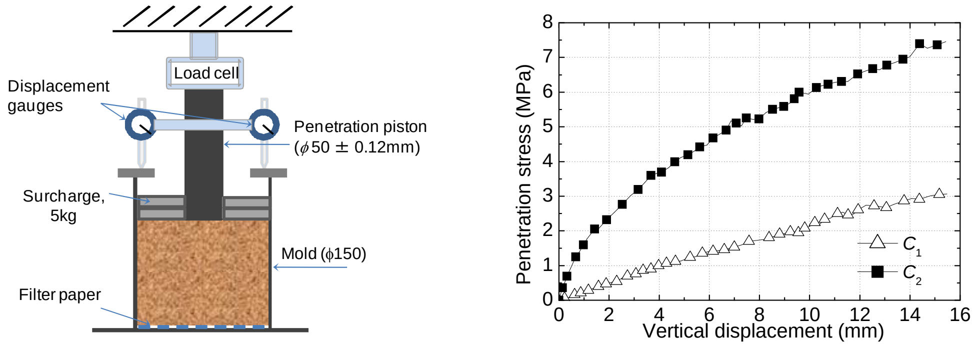
Figure 3: Dry density versus water content: a) C_1 and (b) C_2

3.3 CBR Tests

The specimens were prepared in a cylindrical mold having diameter of 15 cm. The CTGS was compacted by 4.5 kg rammer with 45 cm of dropt height, in three layers and each layer is compacted by 67 blows according the standard JIS A 1211 (1998). The optimum water content of CTGS was not clearly observed based on the results of compaction test. The CTGS was here compacted at natural water content (see Table 2). Table 4 shows the material properties of CTGS before testing.

The apparatus of CBR test is shown in Fig.4.a. The CBR tests on un-soaked specimens were performed using a compression machine with strain rate of 1 mm/min. The readings of total load versus penetration displacement were taken at each 0.5 mm of penetration including the value of 0.5 mm, 2.5 mm and 12.5 mm.

Figure 4.b plots the relation of penetration resistance (penetration stress) vs. penetration for both types of material, C_1 and C_2, where penetration stress is the ratio of penetrating load to cross section of penetration piston. The CBR is defined as the percentage of penetration stress at penetration of 2.5 mm and 5mm to the standard stress of 6.9 MPa and 10.3 MPa, respectively. The CBR value was then selected as the greater value of which were calculated at 2.5 mm and 5 mm penetration. Test results are shown in Table 5.



(a) (b)

Figure 4: (a) CBR test (b) stress-penetration displacement curves

Table 4. Material properties for CBR tests

Material properties	C_1	C_2
Water content (%)	44.95	40.01
Wet density (g/cm^3)	1.63	1.56
Dry density (g/cm^3)	1.13	1.12

Table 5. CBR tests results

Penetration (mm)	Standard load strength (MPa)	Penetration stress (MPa)		CBR (%)	
		C_1	C_2	C_1	C_2
2.5	6.9	0.644	2.765	11.5	40.3
5	10.3	1.185	4.155		

It can be seen that CBR value of C_2 with larger percentage of admixtures is substantially greater than the one of C_1. The influences of water content on CBR value will be investigated in further work though measured CBR values of C_1 and C_2 at the natural water contents are relatively high. Based on ASTM, CBR value of C_1 is relative to CBR value of poor grade sand to medium grade sand, and is evaluated as a fair to good value for subgrade soil. While, CBR value of C_2 is comparative with that of well grade sandy soil or gravel, and classified into good material for subgrade soil.

3.4 Consolidated Drained Triaxial Tests

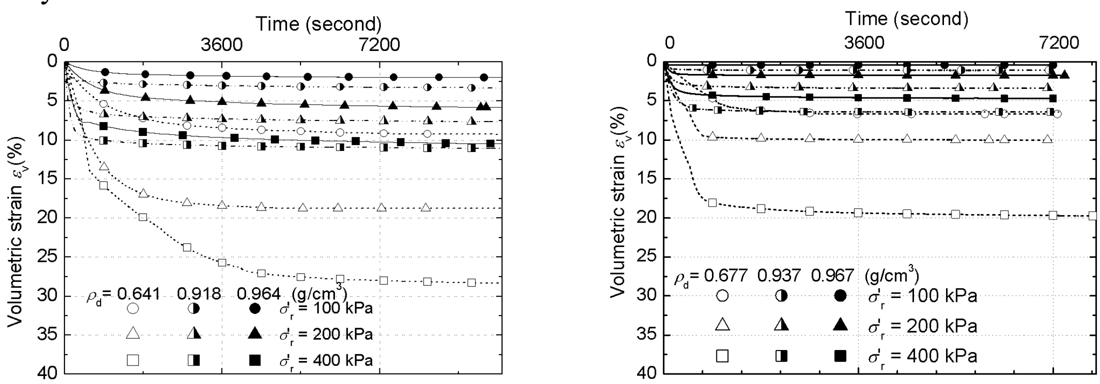
3.4.1 Test Procedure and the Stress-strain Behaviors

A series of CD triaxial tests on loose and dense CTGS specimens was conducted to investigate mechanical behaviors as well as strength and stiffness parameters of the CTGS. Loose specimens were prepared directly into the triaxial cell by using a split mold. CTGS was put into the mold by air pluviation with zero drop height. While, the dense specimens were formed in a steel mold by three layers, and each layer was compacted by 25 or 45 blows of 2.5 kg rammer from 30 cm drop height, corresponding to two levels of compaction energy E_c, as shown in Table 6.

Table 6. Properties of CTGS specimens

Properties	Loose pecimens $E_c = 0$ (kJ/m^3)		Dense specimens, $E_c = 351$ (kJ/m^3)		Dense specimens, $E_c = 632$ (kJ/m^3)	
	C_1	C_2	C_1	C_2	C_1	C_2
Wet density, ρ_t (g/cm^3)	0.930	0.950	1.321	1.311	1.389	1.360
Dry density, ρ_d (g/cm^3)	0.641	0.677	0.918	0.937	0.964	0.967
Void ratio, e	3.33	2.96	2.05	1.82	1.89	1.76

Figure 5 shows the volumetric strain of CTGS specimens versus time during isotropic consolidation at the different initial dry density states corresponding to the two levels of compaction energy. The primary consolidation time t_c was determined by $3t$ method. It is observed that CTGS shows a good permeability, because the primary consolidation in all cases almost finishes within a few hours so that long term is not required to achieve the end of primary consolidation.



(a) (b)

Figure 5: Volumetric strain during the consolidation: (a) C_1, (b) C_2

The stress-strain behaviors of C_1 and C_2 are featured out based on the relations of deviatoric stress, volumetric strain against axial strain in both the loose and dense states as shown in Fig. 6. Although the amount of cement and polymer in C_2 are three times larger than those in C_1, Stress-strain relation and deformation characteristics of C_1 and C_2 exhibited almost same manner, i.e., the stress-strain relation showed the ductile behaviour with no obvious peak strength, and deformation showed the contraction type overall shearing, even in dense states and regardless mixture design. At low confining pressure and dense state, the deviatoric stress of C_1 is relatively smaller than that of C_2 at the initial state of shearing, then gradually enveloped to the one of C_2 at the large strain level. This implies that the larger stiffness of C_2 from the one of C_1 is clearly demonstrated at low confining pressure. It is observed that the

CBR value of C_2 is considerably larger than the one of C_1. Therefore, the effects of mixture design on stiffness of CTGS seem to be clearly appeared at low confining pressure. In addition, it can be seen that the stress-strain curves of both C_1 and C_2 are almost linear at the initial state of shearing then gradually yielded, from which stiffness parameters at small strain level of CTGS could be evaluated.

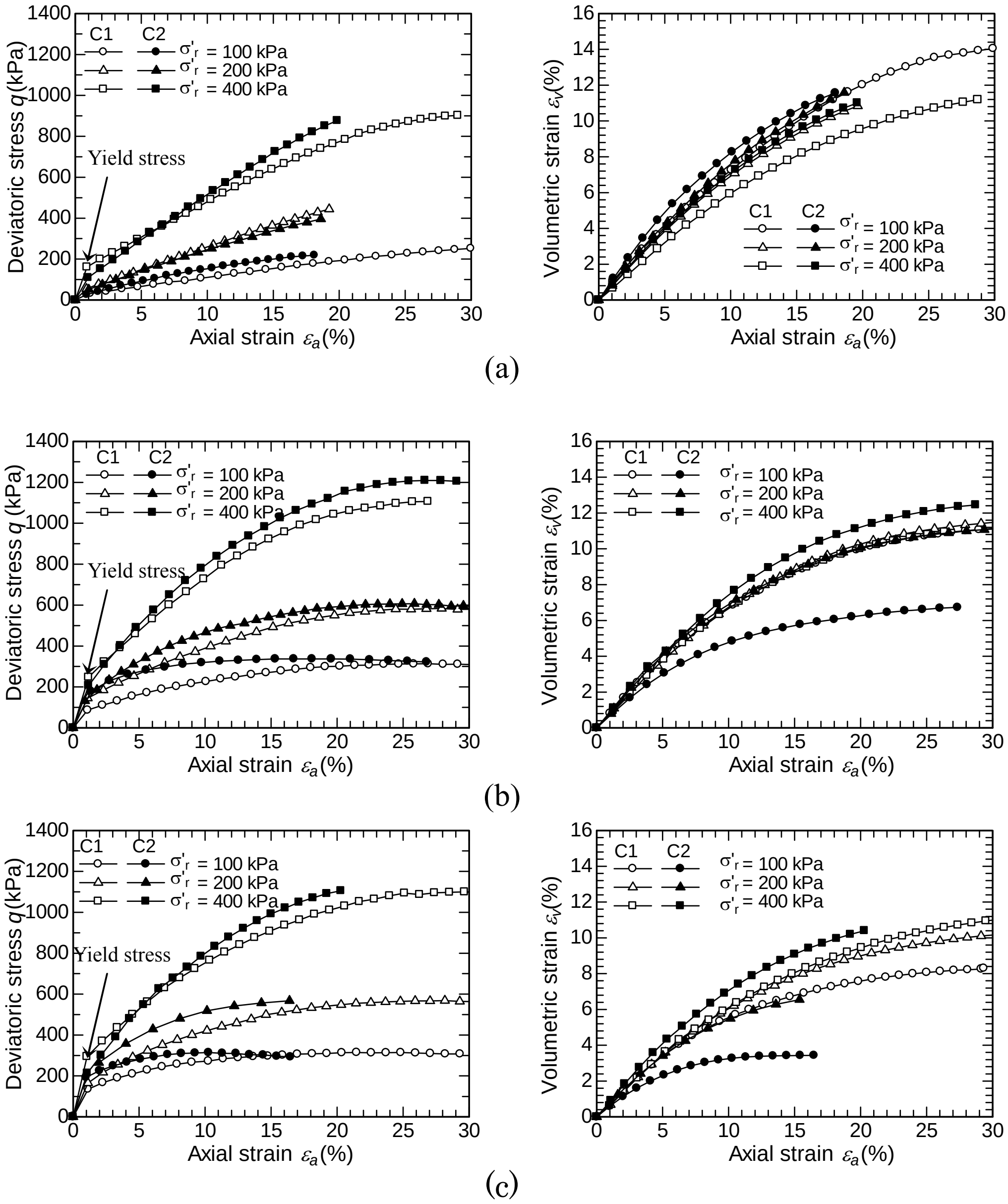
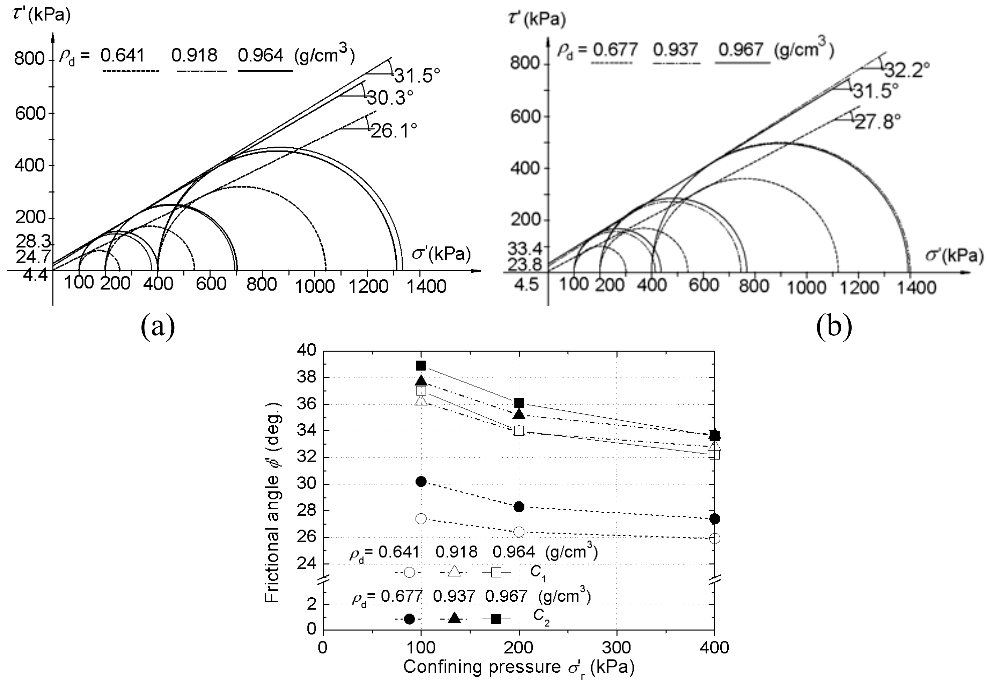


Figure 6: Deviatoric stress and volumetric strain versus axial strain at different confining pressures (a) Loose specimens, $E_c = 0$ kJ/m^3, (b) Compacted specimens with $E_c = 351$ kJ/m^3 and (c) Compacted specimens with $E_c = 632$ kJ/m^3.

3.4.2 Strength and Stiffness Parameters

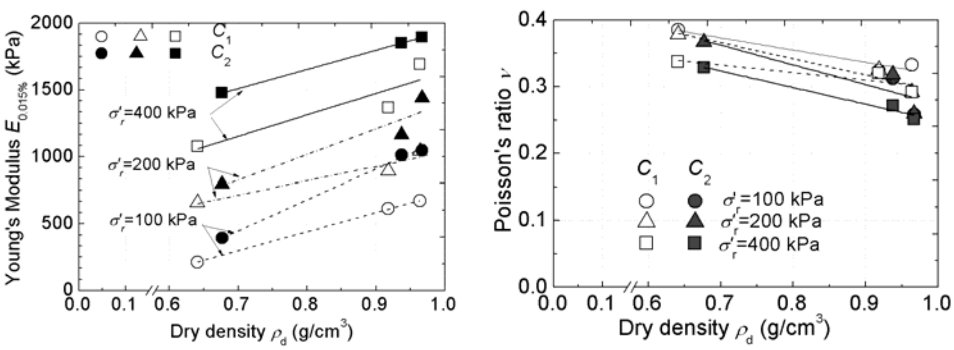
The stress-strain curves of both C_1 and C_2 (Fig.6) do not show any obvious peak strength within wide range of axial strain, the compressive strength, q_{max} is defined as the maximum value of deviatoric stress within a range of $0 < \varepsilon_a \leq 15$ (%) (JGS, 2000). The Mohr's circles and the failure envelope lines of CTGS are plotted in Fig.7. When CTGS is assumed as a pure frictional material that means cohesive strength is assumed to be zero, Figure 7.c shows variation of frictional angle with confining pressure. The decreasing tendency of frictional angle of CTGS to confining pressure is also normally observed in granular material considered as effects of particle crushing when confining pressure increases. It is observed that frictional angle of C_2 is only about 2 degrees larger than that of C_1.



(a) (b)

(c)

Figure 7: (a) Mohr envelope lines of C_1, (b) Mohr envelope lines of C_2 and (c) The variation of frictional angle (ϕ') to the confining pressure.



(a) (b)

Figure 8: Variations of strength parameters with initial dry density and confining pressure: (a) Young's modulus and (b) Poisson's ratio

In order to quantify stiffness parameters, Young's modulus and Poisson's ratio of CTGS are evaluated based on slope of linear part in the stress-strain curves (Fig. 6), and are herein calculated at the axial strain of ε_a = 0.015%. The variations of Young's modulus, $E_{0.015\%}$ and Poisson's ratio, $\nu_{0.015\%}$ with the initial dry density of specimens prior to shearing are presented in Figs. 8.a and 8.b, respectively. It can be seen an increasing tendency of Young's modulus and decreasing tendency of Poisson's ratio with initial dry density and confining pressure, and mixture design.

4 CONCLUSIONS

The experimental framework in this study aims to investigate stress-strain behaviors, strength and stiffness of CTGS at the different mixture design. Although a thorough study is needed to verify the applicability of CTGS for subgrade or basement soil, the results obtained in this study show that CTGS has benefits of granular material (good drainage, ease of compaction), and relative high stiffness and strength parameters that are sufficient to apply for subgrade, embankment or reclamation material, etc. The major conclusions can be drawn as following:

- CTGS is a high porosity, good drainage and lightweight material. CTGS has a high durability against the cyclic wetting and drying though it shows a significant particles crushing due to compaction.
- CTGS could be considered as an ease of compaction material since the water content is not a strongly influencing factor. However, it is quite difficult to increase density because of grain size distribution and high potential of particles crushing.
- Stress-strain behaviour of CTGS under CD triaxial compression exhibits ductile manner regardless mixture design and initial density. The strength and stiffness parameters (Shear parameters (c',ϕ'), Young's modulus, Poisson's ratio and CBR values) of CTGS obtained from the tests indicate that CTGS has competitive stiffness and strength parameter with those obtained from other cement treated soil method using relatively same amount of cement.

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