The performance of soft clay soil stabilized with recycled gypsum in wet environment

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ABSTRACT

The use of recycled gypsum, which is derived from gypsum waste plasterboard, has recently started in Japan and it is a vital to know the durability of soil stabilized with such waste in a wet environment because gypsum is soluble material. The present study investigates the influence of wet environment on the compressive strength, dry unit weight and durability performance of soft clay soil stabilized with recycled gypsum and Furnace cement under the effect of wetting and drying cycles, referred to as wet environment in this study. Standard cylindrical stabilized soil specimens were prepared and cured for 28 days in a controlled room with constant temperature and humidity. After the curing process, the tested specimens were subjected to different numbers of wetting-drying cycles, and then tested for unconfined compressive strength, moisture content and volume change. Results indicated that the unconfined compressive strength increased with the increase of recycled gypsum content for different wetting-drying cycles investigated. The increase of recycled gypsum content is associated with the increase of dry unit weight, as well as decreases of moisture content of stabilized specimens for different cycles of wetting and drying investigated. The unconfined compressive strength of soils stabilized with recycled gypsum and Furnace cement gradually decreases with an increase in the number of wetting and drying cycles, while the early cycles have the greatest effect on the durability compared to the effect of later cycles. Generally, the influence of wetting-drying cycles on the unconfined compressive strength, durability and volume changes of clay soil stabilized with recycled gypsum and Furnace cement is not significant and this is evidence that the use of recycled gypsum to stabilize the soft clay soil achieves acceptable durability. This study indicates the effective use of recycled gypsum, which is derived from gypsum waste plasterboard, contributes to develop a sustainable society reduces the huge quantities of gypsum waste, cut off the cost disposing and meet sound environment.

1 INTRODUCTION

Due to the high economic growth in Japan which started in 1970, the construction industry increased rapidly and thus large amount of construction and demolition wastes were, and continue to be, generated annually. For example, the amount of construction and demolition waste increased from 30 million tons in 1980 to 66.85 million tons in 1992; this means the amount is doubled within 12 years (MLIT). Gypsum plasterboard is one of the most widely construction materials used in the building sector and approximately 1.6 to 1.7 million tons of gypsum waste plasterboard are generated every year in Japan (Ahmed et al. 2010, Kamei et al. 2007).

Plasterboard is made from gypsum sheets covered on both sides with paper sheets. Gypsum waste plasterboard is a serious problem in Japan because the cost of disposal gypsum waste in landfill sites is high. As a result, hazards increase when gypsum wastes are sent to landfill sites due to the emission of hydrogen sulfide and decrease of the area specified for landfill sites. Researchers attempt to find an alternative way to use gypsum waste plasterboard in ground improvement projects instead of disposal in landfill sites; this issue is a recent one in Japan. In order to facilitate the use of recycled Bassanite, which is derived from gypsum waste plasterboard as a stabilizing agent in ground improvement projects, it is essential to know the durability of soil stabilized with recycled gypsum. It is well-known that the recycled gypsum can achieve acceptable strength and stiffness in a dry condition, but it has trouble in either achieving or sustaining the adequate strength to maintain the required loads in a wet environment because gypsum is soluble material. So, there is a need to better understand the strength performance and durability of soil stabilized with recycled Bassanite in wet environments to avoid any negative effect when such wastes are introduced in ground improvement projects. Durability is the property of a geotechnical material that reflects its performance under freeze-thaw and wetting-drying cycles. Freeze-thaw tests should be conducted in the areas that subject to freezing conditions such as in cold regions, while wetting-drying cycles should be conducted in all geographic areas (Zhang and Tao 2006). In general, Japan is considered one of the countries which subject to rainfall in all seasons. As such, the investigation of wetting-drying durability for stabilized soil with recycled gypsum is essential to facilitate the incorporation of recycled gypsum in ground improvement projects.

The main objective of this study is to investigate the effect of a wet environment, referred in this study for wetting-drying cyclic, on the strength of performance and durability of soft clay soil specimens stabilized with recycled gypsum and Furnace cement type-B. For that purpose, the 28 days cured stabilized soil specimens were subjected to different numbers of wetting and drying cycles and then tested for unconfined compression strength, dry unit weight and volume change.

2 MATERIALS AND TESTS

2.1 Materials

The materials used in this study were Kaoline clay soil, Furnace slag cement type-B, and recycled gypsum. The tested soil used was brought from the SINO industrial Clay Company in Japan and the soil used is kaolin clay with approximately 100% Kaolin component. The components of the tested clay soil were clay with a content of 64.7% and silt with a content of 35.3%. The physical and mechanical properties for the tested soil are presented in Table 1. The soil type was classified as clay soil with high plasticity according to the unified soil classification system (USC) and it is classified as clay soil fair to poor (A-7-6) according to the American Association of State Highway and Transportation Officials (AASHTO). Furnace slag cement type-B was brought from Local Cement Company in Japan. This type of cement was produced mainly from the waste materials and the by-product Portland cement, and it is comprised about 30 to 60% furnace slag in its composition. The main cause of using cement in this research is to prevent the solubility of recycled gypsum by developing solidification for the mixture of soil and recycled gypsum. Furthermore, the presence of cement will improve the durability of stabilized clay soil and decrease the leaching effect of heavy metals due to the use of recycled Bassanite (Kamei and Horai 2008). Recycled gypsum used in this research was produced from gypsum waste plasterboard. More details about the production of recycled gypsum from gypsum waste plasterboard were provided in the previous works (Ahmed et al. 2011; Kamei et al., 2007). The air-dried gypsum waste plasterboard were brought from some landfill sites in Japan and then pulverized to obtain the crushed gypsum waste in powder form that is called hydrate calcium sulphate ($CaSO_4$. $2H_2O$). The crushed gypsum waste was sieved to remove any solid portions and paper, subsequently the gypsum waste powder was heated for a certain time at a temperature of 140 to 160 °C to produce the recycled gypsum that is called hemi-hydrate calcium sulphate ($CaSO_4$ $0.5H_2O$) or Bassanite. For each cement-soil ratios of 5% and 10%, four different percentages of recycled gypsum-soil ratios (B/S) of 0, 10, 20 and 40 were used to investigate the effect of both recycled gypsum and cement contents on the strength performance and durability of the tested soil.

Table 1. Physical properties of tested soil

Property	Value	Property	Value
Particle density, ρ_s, (Mg/m^3)	2.680	Liquid limit, LL, (%)	73.10
Plastic limit, PL, (%)	36.70	Plasticity index, Ip	36.40
Silt content, (%)	35.30	Clay content, (%)	64.70

2.2 Sample Preparation

Tap water was added to the oven-dry soil to achieve water content (W/S) of 140% for the tested soil, subsequently the tested soil became very soft clay soil and that the target required in this research. The tested soil was mixed with the water by using an automatic mixer. The mixing process was prolonged for 6 hours to obtain homogenous and isotropic clay soil in Munoz form. The main reason for selecting the water content of 140% is attributed to the soft clay soil found in some locations in Japan, which is very soft and it has approximately the same content of water used herein that is called marine clay. This type of very soft clay soil is spread especially around the Haneda airport area and water content of this soil type, which 140%, was determined by several case records of in situ water contents of seabed clays in Japan (Nakase and Kamei 1984).

The desired contents of Bassanite and furnace cement were mixed by hand in dry state. Soil samples were prepared by mixing the soil with four contents of recycled gypsum (B/S) of 0, 10, 20 and 40% and two cement contents (C/S) of 5 and 10% based on the weight of tested soil as mentioned previously. The required amount of recycled gypsum and cement mixture was mixed into the tested soil by using the automatic mixer and the mixing process was prolonged for 30 minutes to ensure the mixture is uniform. After that, the samples were placed in cylindrical steel mould having internal dimensions of 50 mm in diameter and 100 in height. The moulds were lubricated before placing the samples to ensure no friction between soil samples and the inner sides of the mould developed during sample extraction. The samples were placed in the moulds in five layers and rubber hummer blow was applied in each layer to remove the formation of bobbles within the soil matrix. The samples with moulds were placed in polyethylene bags and kept in controlled room with a temperature of 20°C for 24 hours. The specimens were extracted from the moulds after 24 hours and more care was taken during the extraction of specimens. Subsequently, the specimens were wrapped in polyethylene plastic sheets and then kept in the controlled room for 28 days at temperature 20°C until required for the testing. In order to achieve reliability of the test results, at least three different specimens for each test were prepared and the average was reported in some cases, and in other cases the results of the three specimens plotted in curves to represent the result of one sample. The bulk unit weight for each tested sample was determined.

2.3 Wetting-Drying Test

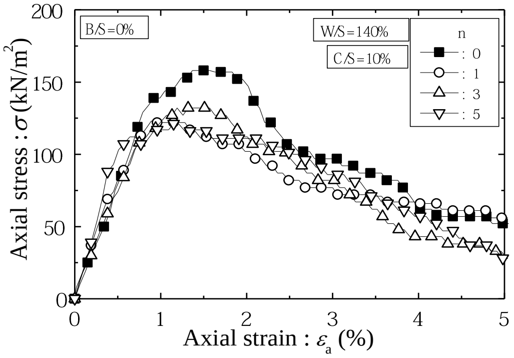
The cycles of wetting and drying were used to evaluate the strength performance and durability of stabilized clay samples with recycled Bassanite. After completing the curing time of 28 days for stabilized specimens the specimens were air dried for 24 hours at room temperature and then immersed completely in the water for another 24 hours. This process represented one cycles of wetting and drying. After completing the required cycles of wetting and drying, the specimens were tested for unconfined compressive strength and the water content was determined for each tested specimens to determine any change in the moisture content. By knowing the water content, the dry unit weight for tested specimen was determined based on the value of bulk density which is previously determined. Volume change was determined after each wetting-drying cycle by measuring the dimensions of sample (diameter and height). Volume change was also determined based on the calculated value of dry unit weight using the value of moisture content for tested samples after subjected the samples for desired wetting-drying cycles. To better understand the effect of wetting and drying cyclic on the strength performance and durability of stabilized specimens, the durability index of the stabilized specimen was considered. It is determined by dividing the ultimate compressive strength of specimen, q_u (n = 1,3,5), after the desired wetting and drying cycles and the ultimate compressive strength for identical specimen subjected only for 28 curing days, q_u (n=0) . The cycles of wetting and dying test were conducted in this research according to the procedures test provided by Japanese Highway Society [JHS 2001].

2.4 Unconfined Compression Test

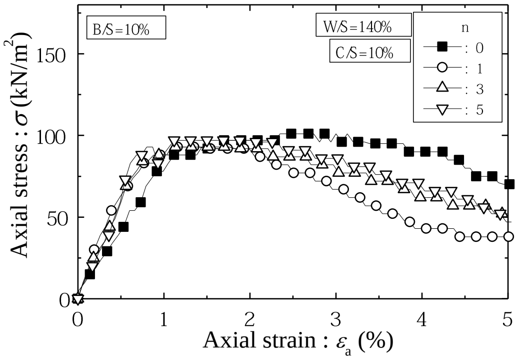
The unconfined compressive strength test was used in this research to evaluate the strength performance and durability of stabilized clay soil with recycled Bassanite subjected to cycles of wetting and drying. Compressive strength is considered one of the most popular methods used to evaluate the performance of soil stabilization as well as one of the main parameters used in the design of earth work projects (Yarbasi et al. 2007). Besides, it is used to evaluate the durability of stabilized soil subjected to weathering conditions (Zang and Tao 2008). For these reasons, the unconfined compressive strength was selected in this study to evaluate the durability of clay soil stabilized with recycled Bassanite. The unconfined compression test was conducted in accordance ASTM D 2166-66. The load was applied to the specimen with a displacement rate of 1 mm per minute and the loading continued applied till the failure of sample occurred or the strain reached to 5%.

3 RESULTS AND DISCUSSION

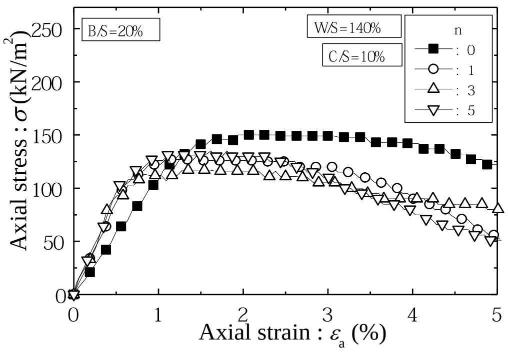
Stress-strain relationships for samples treated with different contents of recycled Bassanite at cement contents of 5 and 10% subjected to 0, 1, 3 and 5 wetting-drying cycles are shown in Figures 1 and 2, respectively. In general, as shown in these figures, the unconfined compressive strength of the tested soil reduces gradually with the increase of wetting-drying cycles for all different investigated cases. The wetting-drying cycles have a large effect on the reduction of unconfined strength in the case of samples treated only with 10% cement content compared to those treated only with content of 5%. It is argued that the tested sample has high moisture content and it is well-known that the increase of cement content in soil matrix is associated with the decease of water content and increase of strength. Thus, the samples treated with 10% cement content have low moisture content and high strength compared to those treated with 5%. Subsequently, the effect of wetting-drying cycles on samples treated with low cement content is not significant because these samples already had adequate amount of water and thus their tendency to absorb more water is null because the voids within soil matrix are already full with the previous water. Subsequently, the effect of wetting-drying cycles is not significant. While in the case of high cement content, the sample became more dry and high strength and then the immersing of samples in water diminishes the bonding between soil particles and cement due to change the structure of the tested sample. Subsequently, the strength reduces with the increase of wetting-drying cycles. In all investigated cases, wetting-drying cycles have much pronounced effect on the reduction of compressive strength especially in the first three cycles; after that, this effect is declined with the increase of number of cycles. This phenomenon can be explained by the exposure of samples to the first numbers of wetting-drying cycles. This rearranges soil particles and the structure of the stabilized soil may be changed. Subsequently, the strength of samples deteriorates with the increase of numbers of wetting-drying cycles up to the third cycle. This concept concurs with the results obtained by previous work which reported the strength declined with increasing the rate of water absorption due to exposed the samples for wetting-drying cycles (Oti et al. 2009). After the third cycle, the particles of stabilized soil may be became stable and accommodate the new condition, subsequently the strength increases slightly due the indirect gain of strength that developed from the gain additional curing for samples during wetting-drying cycles process (Bin-Shafique et al. 2009).



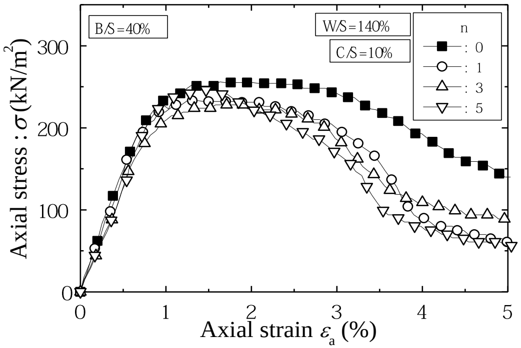
a) Recycled Bassanite content = 0%



b) Recycled Bassanite content = 10%

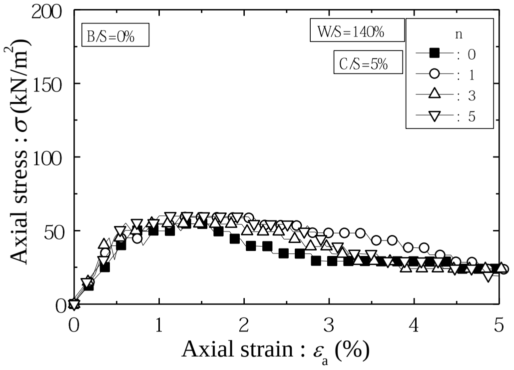


c) Recycled Bassanite content = 20%

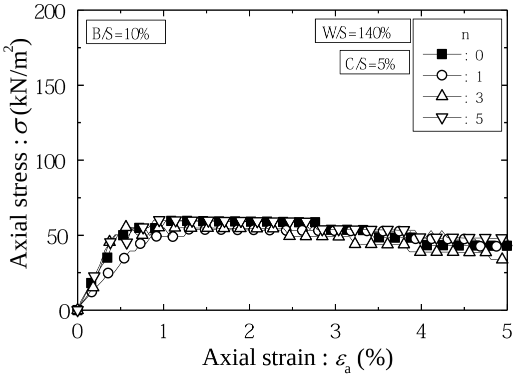


d) Recycled Bassanite content = 40%

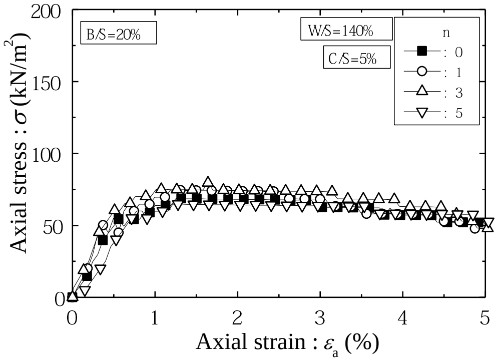
Figure 1. Stress-strain relationships for samples stabilized with different contents of recycled Bassanite and cement content 10%.



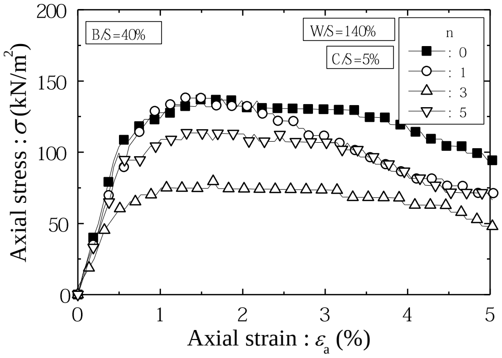
a) Recycled Bassanite content = 0%



b) Recycled Bassanite content = 10%



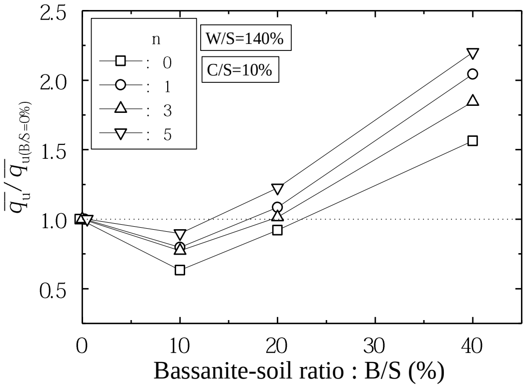
c) Recycled Bassanite content = 20%



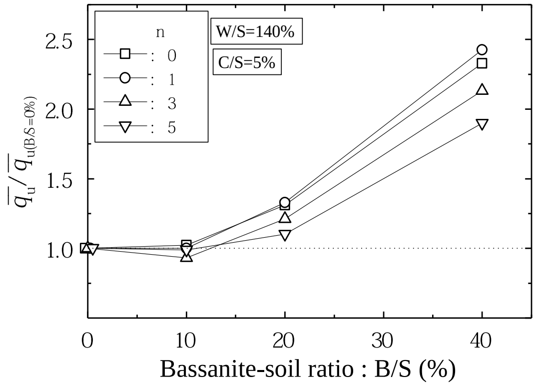
d) Recycled Bassanite content = 40%

Figure 2. Stress-strain relationships for samples stabilized with different contents of recycled Bassanite and cement content 5%.

The additives of recycled Bassanite improved the strength of tested soil for different wetting-drying cycles applied especially in the case of high content of Bassanite as illustrated in Figures 1 and 2. To better illustrate the effect of Bassanite-soil ratio on the enhancement of unconfined strength at the different wetting-drying cycles investigated, the relationship between durability index and Bassanite-soil ratio is determined and presented in Figure 3. Clearly, the increase of Bassanite-soil ratio increases the durability index for different samples stabilized with different Bassanite and cement contents used. This result, which is attributed to increasing the content of recycled Bassanite, develops enough hardness for stabilized samples; subsequently, the samples can resist the action of wetting-drying cycles. The developed hardening for soil samples when recycled Bassanite introduced is attributed to the exchange between calcium ion from the recycled Bassanite and clay particles. Subsequently, the clay minerals flocculate to form stronger blocks of clay fractions that helps to delay the water distribution within soil matrix. Furthermore, the calcium takes place a chemical reaction with the silica and alumina that already existed in the tested clay to produce complex alumates and silicates that improve the strength and durability. Previous studies reported that soils stabilized with some cementation materials which have calcium component improved their strength, especially in the case of cohesive soil (Rogers and Glendinning 1997, Kinuthia et al. 1999, Oti et al. 2009).



a) Cement content = 10%

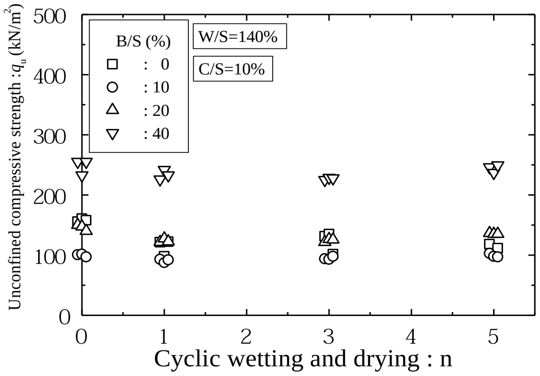


b) Cement content = 5%

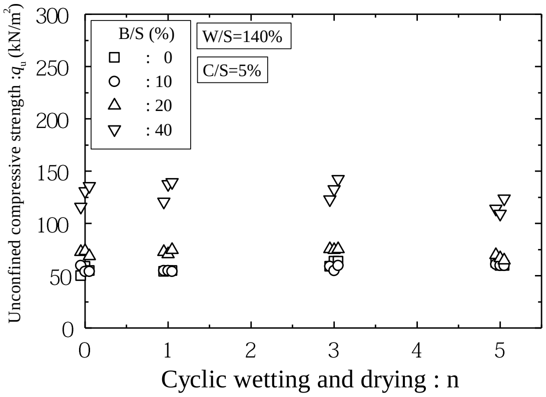
Figure 3. Effect of Bassanite-soil contents/ratios (B/S) on the durability index at different numbers of wetting-drying cycles.

It is clear from Figures 2b and 3a that in the case of samples treated with 10% cement content the durability index and unconfined strength decreased at Bassanite content of 10% compared to the other Bassanite contents used. This behaviour may be attributed to some unknown chemical reaction that takes place between Bassanite, cement and clay minerals and breaks down the developed bonding between soil particles and stabilizing agents, subsequently decreasing the strength. Whilst this reduction in the strength was diminished with the increase of Bassanite content, more than 10% and the better enhancement in both unconfined strength and durability was obtained when the greater percentage of Bassanite-soil ratio was introduced. The same behaviour was provided by the previous work that investigated the effect of recycled Bassanite content on the enhancement of soft clay soil (Kamei and Shuku 2007). They explained this behaviour based on the C_3A (Tricalcium aluminate - $Ca_3Al_2O_4$), which is one of the main components of cement, is occurred or reacted at high heat of hydration by hydration reaction. In this case, Bassanite is used as heat control agent and it acts on reduction in strength as observed in Figure 1-b. This reduction in strength is attributed to the activity of C_3A, which is one of the most parameters responsible for hardening or setting of cement, may be declined due to some chemical reaction takes place between Bassanite and cement (Kamei and Shuku 2007) as occurred in this case with Bassanite content of 10%.

The effect number of wetting-drying cycles on the performance of unconfined strength and durability index are illustrated in Figures 4 and 5, respectively. Figure 4 clearly shows the effect of wetting-drying cycles has not much effect on the unconfined compressive strength for stabilized sample. This is attributed to the main reason mentioned previously - the contents of cement and Bassanite used are capable to resist the actions of wetting and drying cycles. It can be argued that the effect of wetting-drying cycles on the durability of soil stabilized with recycled Bassanite is not significant, as illustrated in Figure 5. In the case of samples treated with cement content of 10%, the durability index decreased slightly with the increase of number of wetting-drying cycles up to the third cycles, and after that the decrease declined with the increase of number of wetting-drying cycles. This behaviour matches with the behaviour of unconfined strength, which was previously explained. Generally, it can be stated that the clay soil stabilized with recycled Bassanite is durable against the actions of wetting-drying cycles.

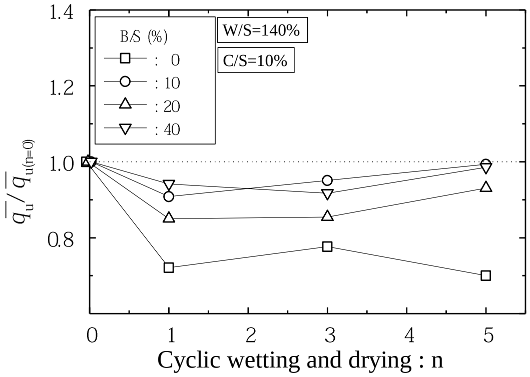


a) Cement content = 10%

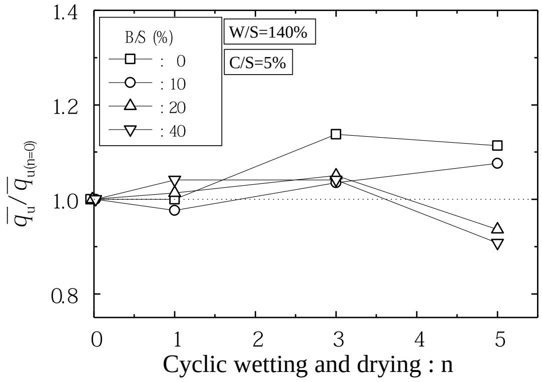


b) Cement content = 5%

Figure 4. Effect of wetting-drying cycles on the unconfined compressive strength for samples stabilized with different Bassanite-soil ratios



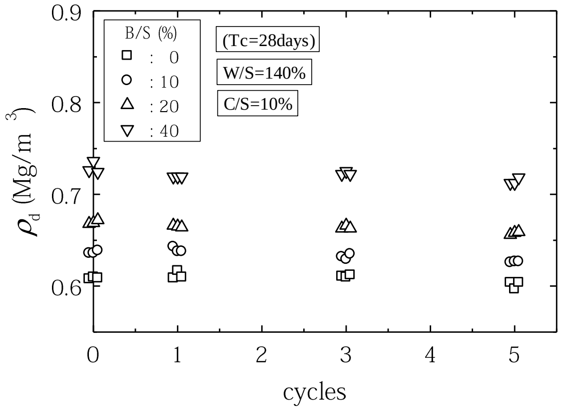
a) Cement content = 10%



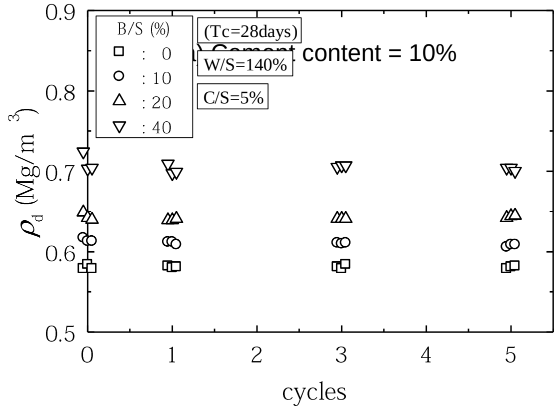
b) Cement content = 5%

Figure 5. Effect of wetting-drying cycles on the durability index for samples stabilized with different Bassanite-soil ratios

Figures 6 and 7 present the effect of wetting-drying cycles on the water content and dry unit weight. It can be stated that the effect of wetting-drying cycles on the water content decrease and dry density increase of clay soil stabilized with recycled Bassanite is not significant. Subsequently, the cycles of wetting-drying have no effect on the volume changes of soil specimens stabilized with recycled Bassanite because the dry unit weight is not changed. The average value for swelling and shrinkage for the stabilized soil sample based on the dimensions measurement of sample after subjected the samples for wetting-drying cycles was found to be 0.01%. This result confirmed the results obtained from the effect of wetting-drying cycles on the water content and dry unit weight of stabilized soil sample with recycled Bassanite. This behaviour is attributed to the reason discussed above; furthermore, the tested soil is composed only of kaolin minerals and it has no any components or minerals which have a sensitive for the swelling.

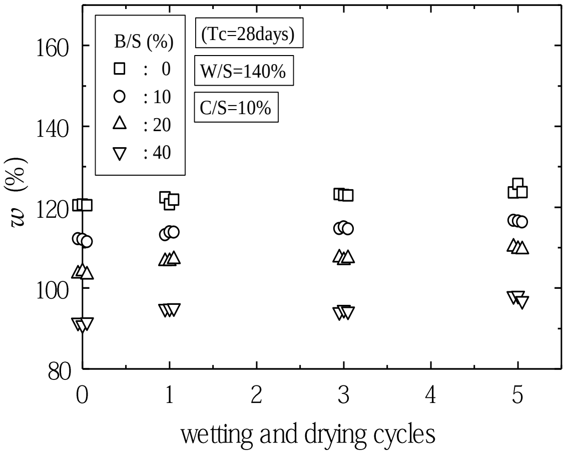


a) Cement content = 10%

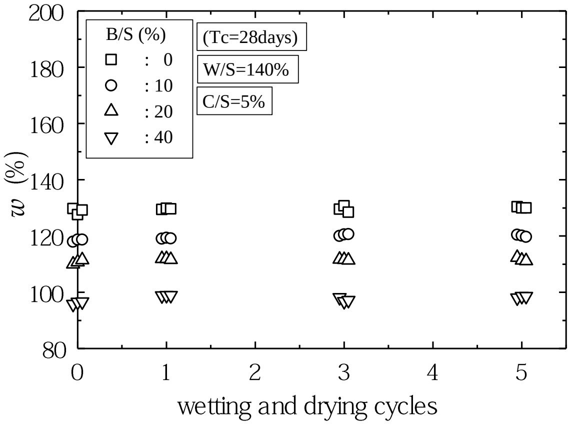


b) Cement content = 5%

Figure 6. Effects of wetting-drying cycles on the dry unit weight of soil stabilized with different Bassanite-soil ratios



a) Cement content = 10%



b) Cement content = 5%

Figure 7. Effects of wetting-drying cycles on water content of soil stabilized with different Bassanite-soil ratios

4 CONCLUSIONS

Based on test results, the following conclusions can be drawn:

1. The additives of recycled Bassanite for soft clay soil improve both unconfined compressive strength and wetting-drying durability of stabilized clay soil. The increase of Bassanite-soil ratio enhanced the strength performance and durability.
2. The effect of Bassanite-soil ratio on the enhancement of durability index and compressive strength is very significant in the case of samples treated with 5% of cement content compared to those treated with 10% cement content especially at the percentage of Bassanite-soil ratio of 10%.
3. By increasing the number of wetting-drying cycles, the unconfined compression strength of all tested samples treated and untreated with recycled Bassanite decreases by an average value of about 10 to 15%.
4. The addition of 40% of recycled Bassanite gives better enhancement in the unconfined compressive strength and improves the wetting-drying durability of stabilized clay soil.
5. With the increase of the number of wetting-drying cycles from 1-3, the unconfined compressive and durability performance decreases. Beyond this range, the compressive strength remains almost unchanged.
6. By increasing of Bassanite-soil ratio, the unconfined compressive strength and durability index increases for different number of wetting-drying cycles applied.
7. The cycles of wetting-drying has no significant effect on water content, dry unit weight and volume change for treated samples with recycled Bassanite.

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