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DURABILITY AND UTILIZATION SYSTEM OF FIBER-CEMENT-STABILIZED MUD PRODUCED FROM CONSTRUCTION SLUDGE

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ABSTRACT

In this study, the durability of the fiber-cement-stabilized mud produced from construction sludge was investigated. In order to use the modified soils as lightweight landfill materials, the durability is very important. Therefore, repeated cycle tests of drying and wetting were carried out. It was found that the durability of fiber-cement-stabilized mud is much higher than that of cement-stabilized mud produced by using the conventional method. It is often said that the durability depends on the generation of the crack in the drying process and it was inferred that the fiber in the mud restrains the generation of the crack. Furthermore, a theoretical equation to estimate the density of fiber-cement-stabilized mud was derived in order to propose the design system to utilize ligh-weight landfill materials.

INTRODUCTION

Construction sludge is the typical high water-content mud and is produced more than 10 million ton per year from the construction sites in Japan. However, the recycling rate of the construction sludge is extremely low. Therefore, we have already developed a new recycling system of high water-content mud by using the paper debris and polymer (BonTerrain Method) in order to increase the recycling rate of the construction sludge(Mori et al., 2003, Takahashi et al., 2003). By using this system, 200-500% water content mud has been modified to the landfill materials by approximately 20 minutes mixing process. The modified soil is called "fiber-cement-stabilized mud" and it has several features. One of the features is lightweight. The fields where lightweight landfill materials are effectively applied will be as follows:

1)The large scale reclaimed works:
Generally, a large amount of soils are used in the reclaimed works. In result, the ground sinkage easily occurs because of the consolidation by the heavy soils. Therefore, utilization of lightweight landfill materials is tried in the upper layer of reclaimed land to decrease the rate of ground sinkage. However, it costs much to make lightweight landfill materials. If the lightweight landfill materials are produced inexpensively from the construction sludge, the cost saving will be significant and recycling rate of the construction sludge will increase largely.

2)A tree-planting on rooftop to prevent heat island:
It is often said that a tree-planting on the rooftop is useful to prevent heat island. In order to plant the rooftop with small trees, the soils have to be carried from the ground to the rooftop. In this case, if the soils are light, the construction will be easy. And easy construction means that large cost saving is possible.

3)Measures works for landslides:
There are many hazardous areas of landslides in Japan. If the heavy soils in the hazardous areas of landslides are replaced by the lightweight landfill materials, the possibility of landslides will be extremely reduced.

In order to use the modified soils as landfill materials, it is very important to know the durability of the modified soils. However, the characteristics of the durability of modified soils produced by BonTerrain method is not made clear yet. Therefore, the objective of this study is to investigate the durability of modified soils through repeated cycle tests of drying and wetting. Furthermore, it is also indispensable to estimate the density of modified soils produced by BonTerrain method. If the density of the modified soils is estimated, it will be possible to control the density of the modified soils by adjusting the water content of construction sludge and to propose the design system to utilize the lightweight landfill materials. Therefore, the second objective is to derive the theoretical equation to and pollutants, some further research will be done about this.

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estimate the density of modified soils.

REPEATED CYCLE TESTS OF DRYING AND WETTING

High-water content mud, such as construction sludge, is in the state which soil particles are distributing in the water. Therefore, by carrying out solidification processing with cement, they can be recycled as landfill materials, and some processing methods have been already proposed. The modified soils produced by the conventional methods are generally called "cement-stabilized mud". However, usually the failure strain of the cement-stabilized mud in the unconfined compression test is much smaller that that of the ordinary soils. This means that quality improvement is not enough for the cement-stabilized mud. In result, the cement- stabilized mud has plentifully the cases of not being suitable for the use as landfill material. For example, Mr. Murata(2002) reported that the adhesion strength of the cement-stabilized mud is extremely small, and they are easily broken at very small stain if the external force acts on the cement-stabilized mud. That is, although the conventional methods are comparatively easy to process, the cement-stabilized mud shows strength properties like concretes or rocks. Therefore, a rigid difference arises between the circumference foundation and new landfill materials by using the cement-stabilized mud. Consequently, in case of an earthquake, the generation of a crack or excessive earth pressure will be a big problem. As mentioned above, in order to produce the high quality modified mud, we have already developed a new recycling method of high-water content mud by using paper debris and polymer. The modified soils produced by this new method are called "fiber-cement-stabilized mud". In this method, as paper debris absorb the great portion of water, it is not necessary to add a lot of cement to the high-water content mud. Furthermore, since the new method uses only a few amounts of polymer to produce the fiber-cement-stabilized mud, it leads to sharp reduction of processing costs. Moreover, since the fiber is included inside the modified mud, the strength of stickness of the fiber-cement-stabilized mud is much larger than that of the cement- stabilized mud (Mori et al., 2003).

By the way, in order to reuse the modified soils as landfill materials, it is very important to know the durability of the modified soils. Repeated cycle tests of drying and wetting have been already conducted for the cement-stabilized mud, and the durability of the cement-stabilized mud was already investigated (Ogawa et al,. 1996). According to the previous works, it was found that the crack produced in the cement-stabilized mud in the contraction process reached the deep inside, and a massive collapse was observed with increasing the cycle numbers of the tests. Furthermore, it is also reported that the unconfined compressive strength of the cement-stabilized mud decreased with increasing the cycle numbers of the tests. Therefore, the previous researches suggested that in the actual construction works, the cement-stabilized mud have to be covered by the ordinary soils so that the cement-stabilized mud may not be exposed in the circumstance. On the other hand, the durability of the fiber- cement-stabilized mud is not made clear as yet. Therefore, in order to examine the durability of the fiber-cement-stabilized mud, repeated cycle tests of drying and wetting were carried out based on the conventional test method.

① Adjustment for water content of imitation mud made of silt and clay (Water content ratio：105%, 150%)

↓

② Addition and agitation of paper debris, powder polymer and chemical flocculants with imitation mud

↓

③ Addition and agitation of cement

↓

④ Initial cure of the modified soils
The modified soils are packed in the chamber and they are kept at 20±3 degrees for three days

↓

⑤ Making specimen
Utilize the general mold(f5cm*10cm)

↓

⑥ Cure of the specimen
The specimens are packed in the chamber and they are kept at 20±3 degrees for seven days

Figure 1. Flowchart of making specimen of fiber-cement stabilized mud.

Figure 1 shows the flowchart of making specimen of the fiber-cement-stabilized mud. Silt and clay were mixed by the weight ratio of 40:60, and the imitation mud was made by adding the water. The amount of water was adjusted so that the water content ratio becomes 105% and 150%. In creation of the cement-stabilized mud, desired cement was mixed to this imitation mud, and then the specimens were made by using the cement-stabilized mud and the standard mold of 50mm diameter*100mm height, and they were cured for 28 days. In creation of the fiber-cement-stabilized mud, paper debris, polymer and chemical flocculants were mixed with the imitation mud. The addition rate of paper debris, polymer and chemical flocculants were 65 kg/m^3, 1.2 kg/m^3 and 8.6 kg/m^3, respectively. The next, the cement was mixed. The addition rate of cement was the same as the cement-stabilized mud. Then, the specimens were made by using the fiber-cement-stabilized mud and the standard mold of 50mm diameter*100mm height, and they were cured for 28 days. After the specimens were made, repeated cycle tests of drying and wetting were carried out. In this experiment, 1 cycle consists of submersion for one day at 20 degrees and drying for two days by 40 degrees. The observation of the surface of the specimens was conducted after each cycle is over, and the unconfined compression test was performed after the 2nd, 6th and 10th cycle is over in order to measure the unconfined compressive strength of the specimens.

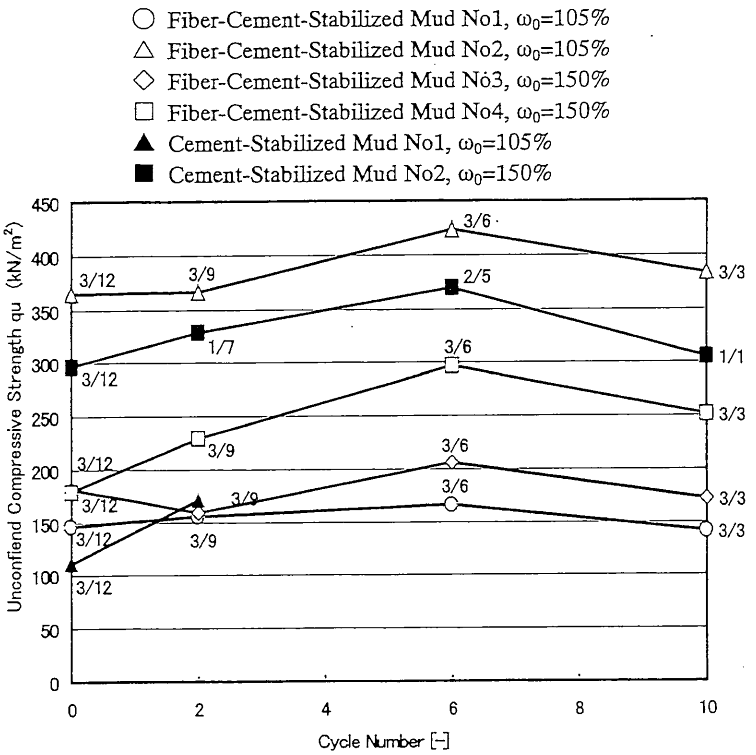

Figure 2. Relationship between the cycle number and unconfined compressive strength in the repeated cycle tests of drying and wetting.

Figure 2 sows the relationship between the cycle number and the unconfined compressive strength in the repeated cycle tests of drying and wetting. The number in Figure 2 shows "the number of samples used in the unconfined compression test / the total numbers of samples before carrying out the unconfined compression test". As for the cement-stabilized mud(ω_0=105%), it was possible to carry out the unconfined compression test and to measure the strength until the 2nd cycle. However, the deterioration was significant and it was impossible to continue the unconfined compression test after the 2nd cycle because all specimens were broken by the terrible deterioration. This result shows the same tendency as the one reported by the previous researchers. On the other hand, the unconfined compressive strength of the fiber-cement-stabilized mud showed approximately the constant value regardless of the increase of the cycle number. The value of the unconfined compressive strength of the fiber-cement-stabilized mud after the 10th cycle was almost the same as the initial unconfined compressive strength, and the deterioration was not observed. It is often said that the durability depends on the generation of the crack in the drying process and it was inferred that the fiber in the mud restrains the generation of the crack.

THEORETICAL CONSIDERATION ON WATER CONTENT AND DENSITY

Water Content Ratio

It is assumed that initial construction sludge consists of soil particles, water and air as shown in Figure 3. In this case, initial water content ratio, ω_0 and the initial density of the construction sludge, ρ_t are expressed as follows:

$$\omega_0(\%) = \frac{m_A + m_W}{m_S} \times 100 \tag{1}$$

$$\rho_t(kg/m^3) = \frac{m_A + m_W + m_S}{V_V + V_S} = \frac{\left(1+\dfrac{\omega_0}{100}\right)\rho_W}{\dfrac{\rho_W}{\rho_S} + \dfrac{\omega_0}{Sr}} \tag{2}$$

$$Sr(\%) = \frac{V_W}{V_V} \times 100 \tag{3}$$

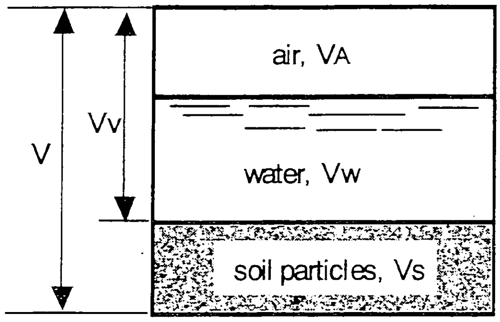

Figure 3 Schematic diagram of initial construction sludge

Here, suffix A,W and S indicate the air, water and soil, respectively. V and m indicate the volume and mass, respectively. ρ_w is the density of the water. m_A is the mass of the air and is assumed to be zero.
Let the addition rate of cement be α[kg/m^3], then the volume of the added cement is expressed by next equation.

$$V_C(m^3) = \frac{\alpha(V_V + V_S)}{\rho_C} \quad (4)$$

Here, ρ_c is the density of cement.
Let the addition rate of paper debris be β[kg/m^3], then the volume of the added paper debris is expressed by next equation.

$$V_D(m^3) = \frac{\beta(V_V + V_S)}{\rho_D} \quad (5)$$

Here, ρ_D is the density of paper debris.
Let the addition rate of powder polymer be γ[kg/m^3], then the volume of the added powder polymer is expressed by next equation.

$$V_P(m^3) = \frac{\gamma(V_V + V_S)}{\rho_P} \quad (6)$$

Here, ρ_P is the density of powder polymer.
Let the addition rate of chemical flocculants be δ[kg/m^3], then the volume of the added chemical flocculants is expressed by next equation.

$$V_L(m^3) = \frac{\delta(V_V + V_S)}{\rho_L} \quad (7)$$

Here, ρ_L is the density of chemical flocculants.

It is assumed that cement is connected chemically with h[%] water of its weight. Furthermore, it is assumed that paper debris contains c[%] water of its weight. Polymer material is the powder(solid), but it is easily soluble in the water. So, the powder polymer is treated as water. Then, theoretical water content ratio of the fiber-cement-stabilized mud, ω is expressed as follows:

$$\omega(\%) = \frac{\dfrac{\frac{\omega_0}{100}\rho_t}{1+\frac{\omega_0}{100}} - \dfrac{h\alpha}{100} + \dfrac{c\beta}{100} + \gamma + \delta}{\dfrac{\rho_t}{1+\frac{\omega_0}{100}} + \left(1+\dfrac{h}{100}\right)\alpha + \left(1-\dfrac{c}{100}\right)\beta} \times 100 \quad (8)$$

Density

In order to use the fiber-cement-stabilized mud as the lightweight landfill materials, it is very important to know the density of the fiber-cement-stabilized mud. Therefore, the equation to estimate the density of the fiber-cement-stabilized mud is derived in this study. It is assumed that the cement volume does not shrink by the reaction with the water. Then, the density of the fiber-cement-stabilized mud, ρ is expressed as follows:

$$\rho(kg/m^3) = \frac{\dfrac{\left(1+\dfrac{\omega_0}{100}\right)\rho_W}{\dfrac{\rho_W}{\rho_S}+\dfrac{\omega_0}{Sr}} + \alpha + \beta + \gamma + \delta}{1+\dfrac{\alpha}{\rho_C}+k\dfrac{\beta}{\rho_D}+\dfrac{\gamma}{\rho_P}+\dfrac{\delta}{\rho_L}} \tag{9}$$

Here, k is the coefficient to express the volume rate of paper debris in the water. The reason why the coefficient, k is introduced in Eq.(9) is that since the water is easily absorbed in paper debris, the total volume of the mixtures of water and paper debris is not equal to the sum of each volume.

Comparison of Calculated Values with Experimental Ones

In this study, specimens of fiber-cement-stabilized mud was made according to the compound ratio shown in Table 1, and the water content ratio and density of the fiber-cement-stabilized mud were measured.

Table 1 Compound ratio to make specimen

ω_0 [%]	α [kg/m^3]	T [day]	β [kg/m^3]	δ [kg/m^3]	γ [kg/m^3]
105	40,80,60,100	7, 28	50	1.2	8.6
150	60,80,100,120	7, 28	60	1.2	8.6

ω_0: initial water content ratio of construction sludge
α: addition rate of cement
T: curing period
β: addition rate of paper debris
δ: addition rate of powder polymer
γ: addition rate of chemical flocculants

Figure 4 shows the relationship between the water content ratio and the addition rate of cement. The symbols in Figure 4 show the experimental results. It can be seen from this figure that water content ratio decreases with increasing the addition rate of cement. The solid lines in Figure 4 show the calculated results from Eq.(8). In the case that the initial water content ratio of the construction sludge is constant, the chemical connection rate of cement with the water, h will decrease with increasing the addition rate of cement. On the other hand, in the case that the addition rate of cement is constant, h will increase with increasing the initial water content ratio of the construction sludge, because high initial water content ratio means that the construction sludge contains plenty of water and cement is easy to connect with water. Therefore, in this study, a following empirical equation for the chemical connection rate of cement with the water, h was obtained based on the above consideration.

$$h(\%) = -\frac{1}{2}\alpha(kg/m^3) + \frac{1}{5}\omega_0(\%) + 90 \tag{10}$$

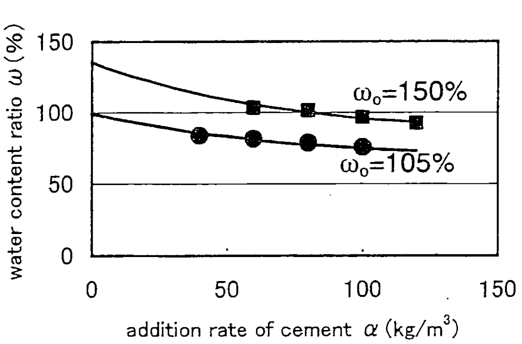

Figure 4 Relationship between water content ratio of the modified soils and rate of cement addition

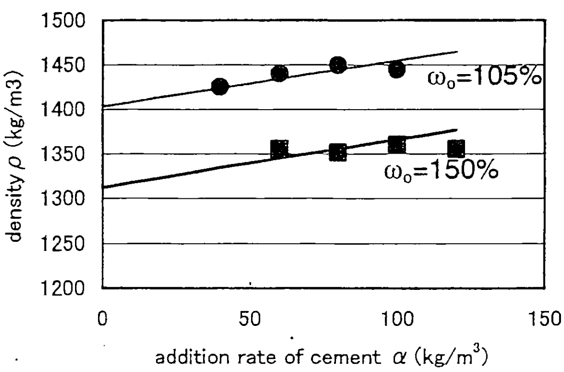

Figure 5 Relationship between density of the modified soils and rate of cement addition

The calculated results are well agreed with the experimental ones. Therefore, the model for the water content ratio is considered to be reasonable.

Figure 5 shows the relationship between the density of the fiber-cement-stabilized mud and the addition rate of cement. The symbols in Figure 5 show the experimental results. It can be seen from this figure that the density of the fiber-cement-stabilized mud decreases with increasing the initial water content ratio of the construction sludge. In this study, the volume rate of paper debris in the water, k was assumed to be 0.5. The solid lines in Figure 5 show the calculated results from Eq.(9). The calculated results are well agreed with the experimental ones. Therefore, the model for the density of modified soils is also considered to be reasonable.

Figure 6 shows the concept of utilization system of lightweight landfill materials produced by BonTerrain Method. In this study, we would like to propose the following system by using the above equations:

1)Measurement of the water content ratio of the construction sludge
2)Determination of the amount of paper debris and polymer based on the measured water content ratio
3)Estimation of the density of fiber-cement-stabilized mud from Eq.(9) based on the amount of paper debris and polymer
4)Design of the construction works based on the estimated density of fiber-cement-stabilized mud.

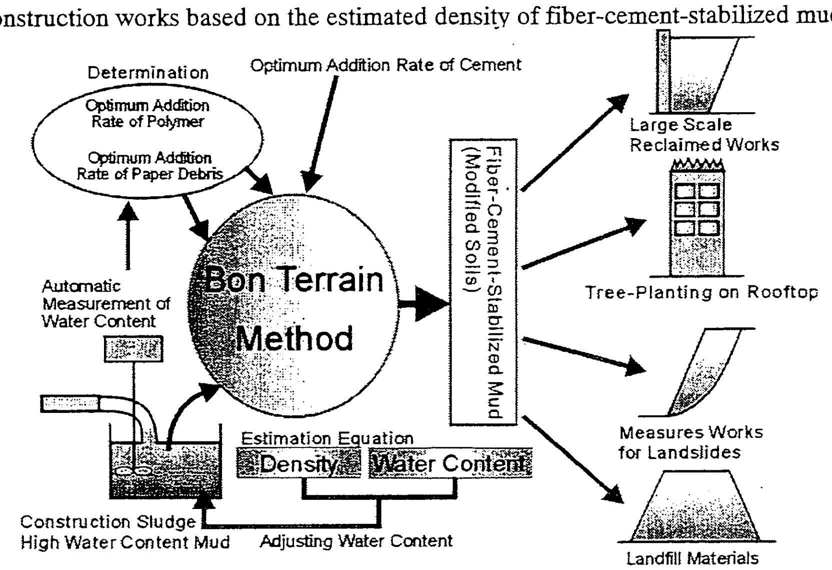

Figure 6 Utilization System of Lightweight Landfill Materials Produced by Bon Terrain Method

CONCLUSIONS

Repeated cycle tests of drying and wetting were carried out by using the cement-stabilized mud and the fiber-cement-stabilized mud, and then the durability of the modified soils was experimentally investigated. It was confirmed that the cement-stabilized mud deteriorated with increasing the cycle number. This result was not inconsistent with the result obtained by the previous researches. On the other hands, it was confirmed that the fiber-cement-stabilized mud did not deteriorate even if the cycle number increased. It is considered that the fiber contained in the mud plays an important role for high durability of fiber-cement-stabilized mud. Furthermore, the equation to estimate the density of the fiber-cement-stabilized mud was derived. It was confirmed that this equation has enough accuracy by comparing the estimated density and actual one of the fiber-cement-stabilized mud. The density is a function of initial water content of construction sludge. Therefore, it becomes possible to control the density of fiber-cement-stabilized mud by adjusting the initial water content. Consequently, a new utilization system of lightweight landfill materials was proposed by using these equations.

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