Study on Strength Characteristics of Rice Straw Fiber-Cement-Reinforced Sludge

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In Japan, “Fiber-cement-stabilized soils method” (FCSS) has studied and applied to recycle dredging sludge from rivers and canals. The method mixed paper fragment and cement into the dredging sludge. The modified-sludge showed some advantages, such as high strength, high durability, friendly environment, and inexpensive. In this paper, FCSS is applied to recycle dredging sludge in Vietnamese Mekong delta. Nevertheless, the cost of paper fragment is becoming too high and also it is difficult to obtain in the delta. Local fiber is strongly desired in order to reduce the recycling fee. Therefore, rice straw is utilized due to its plenty and wasteful amount in Vietnamese Mekong delta. If the paper fragment can be replaced by the rice straw as fiber material, the modified-sludge will be promising able to recycle by FCSS. In this study, unconfined compression tests were carried out to investigate the strength and strain characteristics of the rice straw fiber-cement-reinforced sludge. The results indicated that the rice straw could be used instead of paper fragment in FCSS with high mechanical performances. Moreover, empirical functions were obtained to predict the optimum values for rice straw content and cement content.

Keywords: Sludge, Rice straw fiber, Unconfined compression test, Optimum functions

1 INTRODUCTION

In Vietnamese Mekong delta, it is necessary to dredge canals and rivers annually. This activity is a consequence of settling sediment and soil erosion after rains and flooding seasons. Moreover, the region is affected by climate change, rising of sea level, and salt water intrusion. To control flooding and salinity, dykes have been built and maintained. As results, it takes lots of soils to build the dykes. And, enormous volume of sludge has been disposing. The sludge is mainly transported to landfills with high cost or illegal dumping. Therefore, if the sludge can be recycled for dyke building materials, it will be able to solve the burdens with high transportation cost, illegal dumping, and lack of landfill in the delta. However, it cannot be directly applied for building these dykes because it contains a large amount of water Ref. [1].

In Japan, the “Fiber-cement-stabilized soils method” (FCSS) has been successfully studied and applied by combining paper fragment as fiber material with cement Ref. [2]. The modified-sludge produced by this method has several features such as high failure strength, high failure strain, high durability, and so on. This method has been evaluated highly both on academic and social contribution Ref. [3]. Although, this method is considered as a good processing to recycle the sludge in Vietnamese Mekong delta, it has some difficulties to directly apply the method Ref. [1]. The problems are the increasing of old paper cost and its availability in the delta.

In the delta, agriculture is one of main businesses. Agricultural by-products such as rice husk and rice straw are becoming urgently environmental problems in this area. Annually, the estimated quantity of rice straw in the Vietnamese Mekong Delta is about 26.2 million tons, in which 20.9 million tons was burned directly on the fields and 4 million tons for rice husk Ref. [4]. The source of rice straw is very plentiful. Therefore, locally available fiber materials should be applied for FCSS instead of paper fragment.

The study aims to investigate the effects of adding rice straw fiber and cement on strength and strain characteristics of modified-sludge. Moreover, the applicability of rice straw fiber as local fiber material in FCSS will be discussed. Moreover, empirical functions were obtained to predict the optimum values for rice straw fiber content and cement content.

2 PRINCIPLE OF FIBER-CEMENT-STABILIZED SOIL METHOD

Principles of the Fiber-cement-stabilized soil method by adding rice straw and cement are described as follows:

- Figure 1 (a) simulates a normal sludge. Because of the high moisture property and low yield stress, soil particles can freely move as a “fluid” Ref. [3].
- Rice straw fiber is added to absorb the free water content, and control shrinkage. The free water content of the sludge is decreased as shown in Figure 1 (b).
- Figure 1 (c) shows modified-sludge after adding cement and rice straw fiber. Cement is added to reduce the plasticity and water-holding capacity of the sludge. Hydrate reactions are generated and the sludge’s strength is increased. The cement acts as binding material to combine soil particles and rice straw fiber materials.
3 MATERIALS AND METHODS

3.1 Materials

It is the best to use actual sludge in Vietnamese Mekong delta for this research. However, it is very difficult to bring large amount of actual sludge from the delta to Japan. Therefore, the imitation sludge was decided to use instead of actual sludge. In order to make the imitation sludge, clay and silt should be mixed. However, the mass ratio between clay and silt is the next problem. Therefore, the particles size distributions of some actual sludge samples which are obtained in Vietnamese Mekong delta area were checked. These actual samples were obtained at the real project that is under construction in the delta. In order to imitate the imitation sludge, Kasaoka clay and silt were mixed with its mass ratio of 2:3, respectively. Figure 2 shows the particles size distributions of actual sludge, imitation sludge, Kasaoka clay, and silt. As shown in Figure 2, the particles size distributions of imitation sludge and actual sludge are almost same. This is a reason why the mass ratio 2:3 was chosen. Table 1 shows the properties of imitation sludge, Kasaoka clay, and silt.

The rice straw was obtained in Japan. It has been already confirmed that long and slender rice straw plays an important role to improve the strength characteristics of sludge Ref. [5]. The fiber of rice straw was made from raw rice straw by blender in wet condition. Figure 3 shows the raw rice straw and its fiber. Table 2 shows physical properties of the rice straw fiber. 1135 samples of rice straw fiber were collected to measure its length and width by image processing. Also, 350 tensile tests were conducted in order to investigate the tensile strength of rice straw fiber.

The cement used in this study is “GEOSET 200” that is produced by Taiheiyo Cement Corporation, Japan Ref. [6]. The additive amount of cement is defined as the ratio of cement weight to 1 m³ sludge volume (cement content unit, kg/m³).

3.2 Experimental Methods

The conventional unconfined compression tests were employed. Table 3 shows the mixing conditions. In this study, the target values for failure strain and failure strength were set to be more than 5% and more than 120 kPa, respectively Ref. [7]. The procedure is described as follows:

- Imitation sludge was made by mixing clay, silt with water. Cement and rice straw were added to make the modified-sludge. The modified-sludge was cured at 20 ± 3°C for 3 days.
- Specimens were made by compaction method with cylinder mold of 100mm in height and 50mm in inner diameter. The specimens were compacted by four layers (5 times for the first layer, 10 times for the second layer, 10 times for the third layer, and 20 times for the final layer) with hammer (1.5kg in weight and 200mm in free-fall height). Specimens were cured for the next 7 days at 20 ± 3°C.
- Carry out unconfined compression tests.

In the table 3, the initial water content of modified-sludge was set from 40% to 80%. For each initial water content condition, several cement content conditions were tested. And also, for each cement content condition, several amount of rice straw content conditions were carried out.
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Figure 4  Compressive results of modified-sludge

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4 RESULTS AND DISCUSSIONS

Figure 4 in the previous page shows the compressive results of the modified-sludge. Compared to the strength of cemented-sludge (sludge with adding cement only), the adding of rice straw fiber can increase or decrease the compressive strength of modified-sludge. The conclusion can be detected from the changing of compressive strength by adding of additive amount of rice straw from 0 to 5 kg/m$^3$. The results were driven by the ratio of rice straw and cement ($K$). $K$ is defined as the ratio of additive amount of rice straw and cement in percentage. Figure 5 shows the results of $K_b$. $K_b$ is defined as the ratio of additive amount of rice straw and cement in percentage at conditions which adding of rice straw reduced the compressive strength when it compared to the strength of cemented-sludge (at 0 kg/m$^3$ rice straw adding). $K_b$ is a function which depends on initial water content of the sludge. For each initial water content of sludge, if the ratio of additive amount of rice straw per cement ($K$) is higher than $K_b$, the adding of the rice straw will increase the compressive strength of the modified-sludge and conversely. Figure 5 shows that with increasing the initial water content of sludge, $K_b$ is decreased. This is because the strength of sludge is weaker at higher initial water content so that the value of $K$ is low enough to increase the compressive strength of modified-sludge.

The effect of rice straw inclusion on compressive strain is to increase the strain of the modified-sludge. In other words, it reduced the brittle property of cemented-sludge.

From the compressive results and 2 target values, optimum conditions for additive amount rice straw and cement can be withdrawn. The optimum condition is defined as the lowest additive amount of materials into the sludge which satisfying 2 target values. The optimum condition results were shown in Table 4. In actual works, the initial water content of sludge can easily be obtained. And from the initial water content, the optimum values of additive amount of rice straw and cement can be determined.

Figure 6 shows the results of optimum conditions for cement content and rice straw content. Eqs.(1) and (2) show the relationship between initial water content of the sludge ($w$) and optimum cement content ($C$), rice straw fiber content ($RS$).

| Initial water content (%) | Amount of cement (kg/m$^3$) | Amount of rice straw (kg/m$^3$) |
|---------------------------|-----------------------------|---------------------------------|
| 40                        | 10, 0, 5, 10, 20, 30         |                                 |
| 50                        | 30, 0, 5, 10, 20             |                                 |
| 60                        | 35, 0, 5, 10, 20, 30         |                                 |
| 70                        | 40, 0, 5, 10, 20             |                                 |
| 80                        | 45, 0, 5, 10, 20, 30         |                                 |

$$C = -0.0214w^2 + 3.3714w - 88.857$$
$$R^2 = 0.96$$

$$RS = -0.19w + 33.2$$
$$R^2 = 0.93$$

Figure 6 shows that the optimum values of cement content increase with increasing of water content. However, the optimum additive amount of rice straw will be decreased with increasing of the water content. This is because with more water, the sludge needs more cement to obtain enough compressive strength. And with more water in the sludge, the sludge becomes more plastic so it does not need more rice straw to increase the compressive strain.
5 CONCLUSIONS

The effects of adding rice straw fiber on compressive strength of cemented-sludge depend on the mass ratio of rice straw and cement ($K$). With an initial water content of sludge, if the ratio of adding of additive amount of rice straw per cement ($K$) is higher than $K_{c}$, the adding of the rice straw will continuously increase compressive strength of the modified-sludge and conversely.

The effect of rice straw inclusion is to increase the compressive strain of the modified-sludge. In order words, it reduced the brittleness of cemented-sludge.

Furthermore, two empirical equations to predict the optimum additive amount of rice straw fiber and cement as function of initial water content of sludge were derived.

In perspective of compressive strength and strain, the rice straw fiber can be used instead of paper fragment in FCSS to recycle the sludge in Vietnamese Mekong delta.

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