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Reuse of construction waste for backfill material sorted by self-sedimentation

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ABSTRACT: Increasingly, construction waste, such as high-water-content clay and sand slurry, is being mixed with cement for use as backfill material. The mechanical properties of such mixture depend highly on the grading characteristics of the soil particle. To ensure backfill material of sufficient strength, it is important to control the grading characteristics of construction waste. In this study, the self-sedimentation of construction waste mixed with water is used to obtain sand and clay materials sorted to the desired particle grading. An experimental study was carried out to understand the relationship between slurry density and mixing time.

1 INTRODUCTION

Japan's construction industry consumes half of all the resources used as construction materials in the country. On the other hand, half of the domestic industrial waste finally disposed is related to the construction industry. Japan has a shortage of waste disposal sites. Furthermore, construction engineers must consider environmental issues when they deal with waste. These circumstances require to minimize waste and maximize the reuse of materials.

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Construction waste is generated in various kinds of excavation work. For instance, construction waste from underground slurry shield tunnel excavation is treated as industrial waste because of its very high water content. The Ministry of Construction (now called the Japanese Japanese Ministry of Land, Infrastructure and Transport) proposed in 1997 to make use of such construction waste by turning it into backfill material. For example, one type of backfill material is made through a Liquefied Soil Stabilization (LSS). In this material, clay and sand slurry are mixed with cement to create stable treated soil that is suitable for use as backfill. The physical properties of backfill material depend highly on the characteristics of the construction waste from which it is derived. The grain size is especially closely related. Therefore, a technique is needed to sort the grain size of construction waste.

This study aims to develop a way to make backfill material from high-water-content construction waste. The authors propose a method that uses circulation in a tank and the resulting self-sedimentation in order to sort granular waste material by grain size. This method is expected to produce a great deal of backfill material with desired grain distribution at a single time. In this paper, we conduct laboratory testing of sorting by self-sedimentation of material in a tank. The results of the sorting are quantified, and the criteria involved in the treatment process are discussed.

2 LABORATORY TEST

2.1 *Test Apparatus*

Figure 1 shows the testing apparatus used in this experiment. The apparatus consists of a tank and a pump. The tank size is 640 × 440 × 380 mm. The specifications of the pump are indicated in Table 1. A cylindrical sampler (internal diameter 50 mm, length 500 mm) is used for extracting the sample.

2.2 *Physical properties of test sample*

The physical properties of the construction waste sample used for this test are shown as follows. Table 2 indicates the results of grain size analysis of the sample. Table 3 shows the values of the density of soil particles (ρ_s), plastic limit (PL), liquid limit (LL), plasticity index (PI), and pH of the sample.

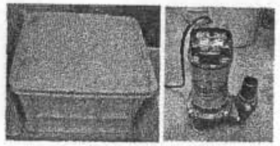

Figure 1. Test Apparatus.

Table 1. Specification of pump.

Caliber	40min
Expulsion speed	40~170 l/min
Pumping height	2.0~6.0m
Rating voltage	100V
Rating frequency	50Hz
Rating power output	0.25kw
Rating electric current	4.7A
Pole	2P
Rating electric power consumption	405W

Table 2. Grain size analysis of the sample.

Grain size (mm)	Percentage (%)
19	100.0
9.5	100.0
4.75	100.0
2	100.0
0.85	99.9
0.425	98.9
0.250	91.2
0.106	63.4
0.075	56.3
0.047	51.5
0.034	44.5
0.022	31.2
0.013	15.8
0.009	14.7
0.006	13.3
0.003	13.0
0.001	13.0

Table 3. Physical properties of the sample.

ρ_s	2.70g/cm^3
PL	126.19%
LL	131.10%
PI	4.91%
PH	10.23

2.3 *Test procedure*

The test is carried out as follows:

1 Put construction waste sample into tank (Figure 2^a).

2 After compounding with water, adjust the mixture to a predetermined density ρ (Figure 2^a).

3 Mix the water and waste sample using the pump (Figure 2^b).

4 Stop mixing at a predetermined time and leave the mixture to settle (Figure 2^c, 2^d).

5 After a predetermined time, remove the top clear layer of water and extract the sample by cylindrical sampler.

6 Divide the sedimented sample into five layers and investigate the grain size distribution of each layer.

The test conditions are as follows. The samples have three patterns of predetermined density ρ (1.45, 1.7, 1.9 g/cm^3), and the predetermined mixing time t for each density also falls into three patterns (2, 4.5, 9 min). Therefore, nine cases are examined in this test. The samples were obtained from a construction-waste treatment facility in Ichikawa city, Chiba Prefecture, Japan.

3 TEST RESULTS

The results of the tests performed according to these procedures are shown in Figures 3-11.

These figures result from the grain size analysis of each case. In each figure, the five curves indicate the five layers, numbered from the bottom to the up. The distribution curve of grains that were 75 μm or less is not shown in these figures, because such grains make up a very small proportion of the grains in sedimentary mud.

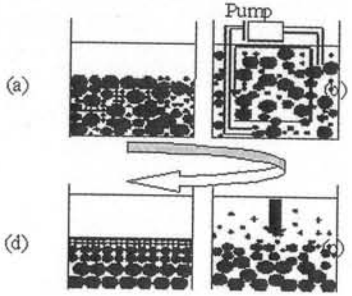

Figure 2. Experimental procedure.

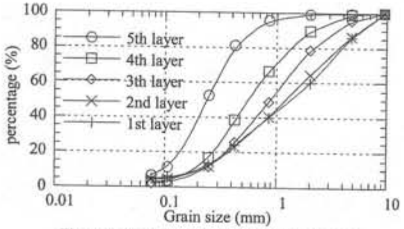

Figure 3. Grain size distribution of each layer

(Density 1.45 g/cm^3 ; Mixing time 2 min)

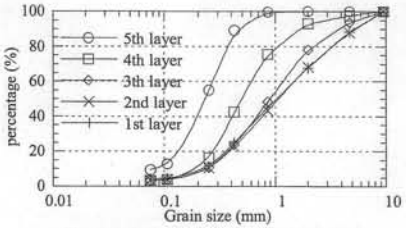

Figure 4. Grain size distribution of each layer

(Density 1.45 g/cm^3 ; Mixing time 4.5 min)

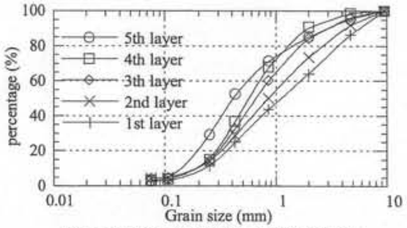

Figure 5. Grain size distribution of each layer

(Density 1.45 g/cm^3 ; Mixing time 9 min)

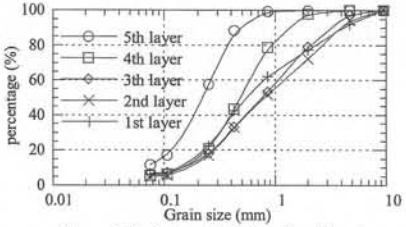

Figure 6. Grain size distribution of each layer

(Density 1.7 g/cm^3 ; Mixing time 2 min)

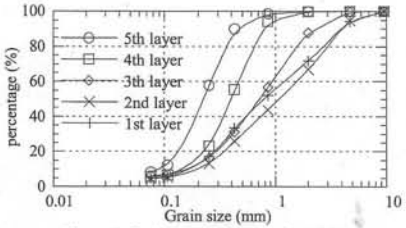

Figure 7. Grain size distribution of each layer

(Density 1.7 g/cm^3 ; Mixing time 4.5 min)

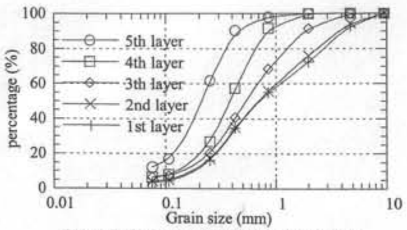

Figure 8. Grain size distribution of each layer

(Density 1.7 g/cm^3 ; Mixing time 9 min)

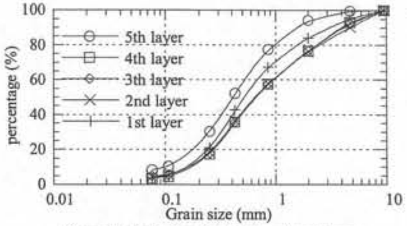

Figure 9. Grain size distribution of each layer

(Density 1.9 g/cm^3 ; Mixing time 2 min)

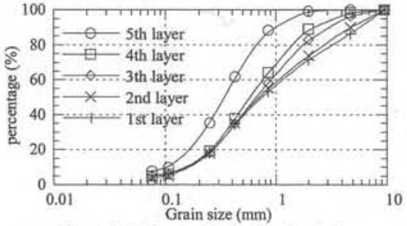

Figure 10. Grain size distribution of each layer

(Density 1.9 g/cm^3 ; Mixing time 4.5 min)

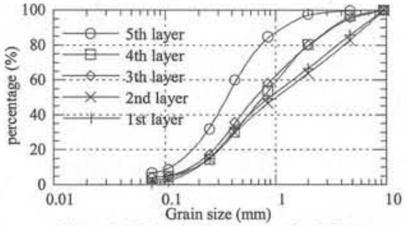

Figure 11. Grain size distribution of each layer

(Density 1.9 g/cm^3 ; Mixing time 9 min)

4 EVALUATION OF SORTING EFFICIENCY

This test is performed by circulating the slurry and then sorting according to differences in the self-sedimentation rate. Therefore, to evaluate the sorting efficiency, it is necessary to consider the grain size distribution of each layer and the mixing power.

4.1 *Quantification of sorting efficiency*

Sorting efficiency is quantified by the following equation.

$$K = k \times R \tag{1}$$

where: K is the parameter of sorting efficiency; k is the apparent parameter of sorting efficiency; and R is the coefficient revising dispersion of the grain size distribution.

k is obtained as follows.

1 Obtain the mean grain size d_{50} of each layer from the results of the grain size analysis (Figures 3-11).
2 Obtain the depth ratio h to height of sedimentary soil at about the middle point of each layer. From this, h comes to 0.1 in the first layer, followed by 0.3, 0.5, 0.7 and 0.9 in the successive layers.
3 Plot d_{50} at the ordinate in a logarithmic scale and h at the abscissa in a geometric scale.
4 Draw an approximate straight line on the plots.
5 Obtain the slope of the straight line. The absolute value of the slope is k.

This procedure is performed on each test result, shown in Figures 3-11. The results of this procedure are indicated in Figures 12-20. R is a correlative coefficient of this approximate straight line. The value multiplying k by R is the actual sorting efficiency K. Table 4 shows the values of k, R, and K in the nine cases.

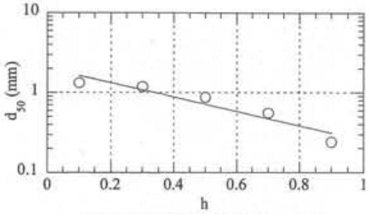

Figure 12.Relation between d_{50} and h

(Density 1.45 g/cm^3 ; Mixing time 2 min)

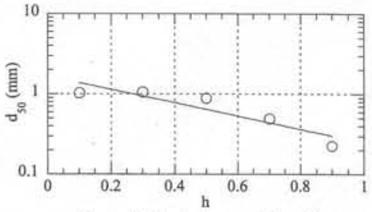

Figure 13.Relation between d_{50} and h

(Density 1.45 g/cm^3 ; Mixing time 4.5 min)

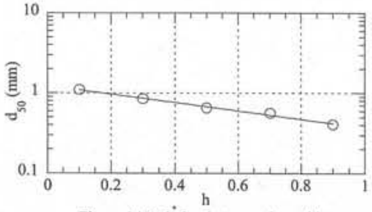

Figure 14.Relation between d_{50} and h

(Density 1.45 g/cm^3 ; Mixing time 9 min)

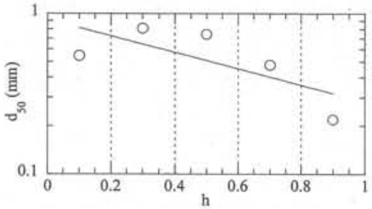

Figure 15.Relation between d_{50} and h

(Density 1.7 g/cm^3 ; Mixing time 2 min)

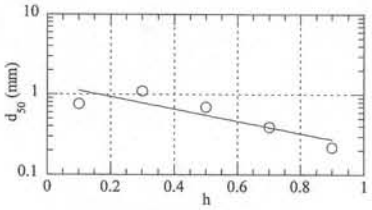

Figure 16.Relation between d_{50} and h

(Density 1.7 g/cm^3 ; Mixing time 4.5 min)

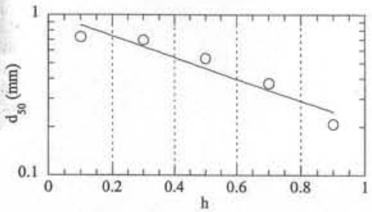

Figure 17.Relation between d_{50} and h

(Density 1.7 g/cm^3 ; Mixing time 9 min)

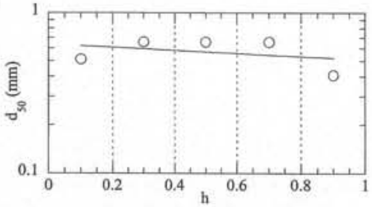

Figure 18.Relation between d_{50} and h

(Density 1.9 g/cm^3 ; Mixing time 2 min)

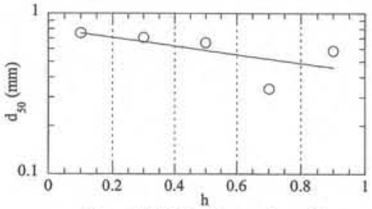

Figure 19.Relation between d_{50} and h

(Density 1.9 g/cm^3 ; Mixing time 4.5 min)

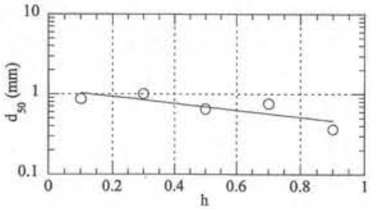

Figure 20.Relation between d_{50} and h

(Density 1.9 g/cm^3 ; Mixing time 9 min)

Table 4. Values of k , R and K in nine cases.

Mixing time \ Density		1.45	1.7	1.9
9min	k	1.207	1.561	1.003
	R	0.997	0.936	0.763
	K	1.203	1.462	0.765
	A	7.199	1.190	0.338
4.5min	k	1.911	1.765	0.619
	R	0.856	0.733	0.699
	K	1.635	1.294	0.432
	A	3.599	0.595	0.169
2min	k	2.082	1.180	0.220
	R	0.935	0.562	0.255
	K	1.947	0.663	0.056
	A	1.600	0.264	0.075

4.2 *Quantification of mixing power*

It is considered that Camp's equation (1953) can be used to calculate mixing power. This equation is known for its role in the design of flocculation tanks in water purification processing. Camp's equation is shown below.

$$G_t = t\sqrt{\frac{P}{\mu_s V}} \tag{2}$$

where: G_t is the parameter of mixing power; t is the mixing time (sec); P is the pumping power (W); μ_s is the coefficient of viscosity; V is the container volume (m^3). μ_s is known for relating linearly with the density of samples here, since the construction waste used in this test is in a state of slurry with very high water content.

From Equation (2), it can be observed that G_t value is in proportion to time and is in inverse proportion to the square root of the density. However, Table 4 indicates that K value is much more dominated by the density ρ than by the mixing time t. For this reason, the following can be considered. If each soil particle is dispersed by mixing once, then mixing power is unrelated to mixing time.

To accommodate this point, the authors assume the experimental equation below.

$$\mu_s = C \times \rho^{22.634} \tag{3}$$

where: μ_s is the coefficient of viscosity; ρ is the density of soil particles; C is the constant. Equation 3 is obtained by noting the two pairs (ρ=1.9 g/cm^3, t=9 min; ρ=1.7 g/cm^3, t=2 min and ρ=1.7 g/cm^3, t=9 min; ρ=1.45 g/cm^3, t=2 min) in which K between the pairs is similar.

C is equal to 1; substituting Equation 3 for Equation 2 yields the following equation.

$$G_t = t\sqrt{\frac{P}{\rho^{22.634} \times V}} \tag{4}$$

A is used instead of G_t, and it is as follows.

$$A = t\sqrt{\frac{P}{\rho^{22.634} \times V}} \tag{5}$$

where:A is the mixing power. Table 4 indicates the value of A obtained by Equation 5 for each case.

4.3 *Relationship between sorting efficiency and mixing power*

In Section 4.2, Equation 3 is obtained by observing that a correlation between K and A exists in four of the test cases. Therefore, it is necessary to investigate whether or not this observation fits all nine test cases.

Figure 21 presents the values of K and A of each case, as indicated in Table 4, in either logarithmic scale. This figure proves that K becomes larger with the increase in A and hardly varies when A is larger than 0.70.

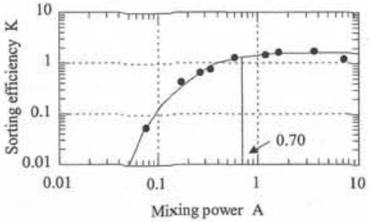

Figure 21. Relation between K and A

4.4 *Investigation of sorted sample for backfill material*

It must be investigated whether or not the sample sorted by using this test is appropriate for reuse. In the case of LSS, taken up earlier as an type bf backfill material, the requirement are as follows: the proportion of fine-grained soil is more than 16% (Goto et al., 1996), the greater proportion of sand is preferred (Ohnaka et al., 2000), and there is no gravel over 20 mm (Kasai, 1999). Table 5 indicates an example of the grain size distributions of sorted samples. From this table, it is observed that the procedure performed in this test can make materials that meet these conditions. Compressive strength, which is important for backfill material, is increased by increasing the proportion of sand. Therefore, it is considered that the test by self-sedimentation in a tank through circulation is effective for producing material suitable for use as backfill.

Table 5. Grain size analysis of sorted samples (an example).

Coarse gravel	0.0%
Medium gravel	1.6%
Fine gravel	6.5%
Coarse sand	33.3%
Fine sand	41.4%
Silt	11.6%
Clay	5.6%

5 CONCLUSION

This study presented a method for sorting material by self-sedimentation in a tank through the use of circulation, and demonstrated the method's suitability for converting construction waste into backfill material. The ability to obtain a moderate sorting efficiency K proves that samples with uniform grain size can be selected through this test procedure. Therefore, the test procedures in this study can be utilized for the reuse of construction waste for backfill material. It was also proved that sorting efficiency K correlates with the mixing power A but K has an upper limit value. This indicates that there is an optimum mixing power A to obtain the highest sorting efficiency. Therefore, A can be applied to the design and the operational criteria for the treatment plant.

The conclusions derived from this study are as follows:

1 Self-sedimentation with pump mixing is an effective way to obtain sand material with particles in a specific range of diameters.
2 As the mixing power increases, there is an upper limit to sorting efficiency.

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