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Strength properties of air-formed lightweight soils with various types of short fibers

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ABSTRACT: Air-formed lightweight soil is made by mixing air bubbles into cement-treated soil. The air-formed soil is a geomaterial with high rigidity and strength, so that it shows usually brittle behavior in deformation-strength property. It is expected that the brittle behavior of the air-formed soil will be improved by mixing short fibers. In order to investigate improvement effect on the strength of air-formed lightweight soil due to mixing short fibers, triaxial compression tests were performed. Three kinds of short fibers are used (nylon threads, waste paper and PET short fibers). Nylon thread is used in place of waste fishing net, waste paper fiber is made by breaking into flocculate, and PET short fibers are a recycle material from waste PET bottle. Increase of residual strength of the air-formed lightweight soil by mixing short fibers and improvement in stress-strain behavior were clarified. It was also confirmed that short fibers made from waste materials is useful for improving the brittle behavior of air-formed lightweight soil.

1 INTRODUCTION

Air-formed lightweight soil is usually made by mixing sand or original soil with water, hardening agent and air bubbles. The main features of the soil are (i) lightweight (wet density between 0.6 and 1.2 g/cm^3), (ii) adjustable strength (unconfined compressive strength between 300 and 1000 kPa), (iii) fluidity before hardening. The air-formed soil is a geomaterial with high rigidity and strength because of containing large amount of hardening agent for obtaining required strength. It is therefore expected to improve mechanical property of the air-formed soil, particularly for using original soil such as soft soil or surplus construction soil.

The authors presented that mixing PET bottle pieces or fishing net threads is effective for increase of residual strength or tensile strength of cement-treated soil (Omine et al., 2001). It is also considered that mechanical properties of the air-formed lightweight soil will be improved by mixing short fibers. From the environmental point of view, use of short fibers made from waste material is promoted. Three kinds of short fibers are used, namely nylon threads, waste paper and PET short fibers. Improvement in brittle behavior regarding deformation-strength property is discussed based on triaxial compression test of the air-formed soil with various types of short fibers (Takayama et al., 2005).

2 USED MATERIALS AND EXPERIMENTAL PROCEDURE

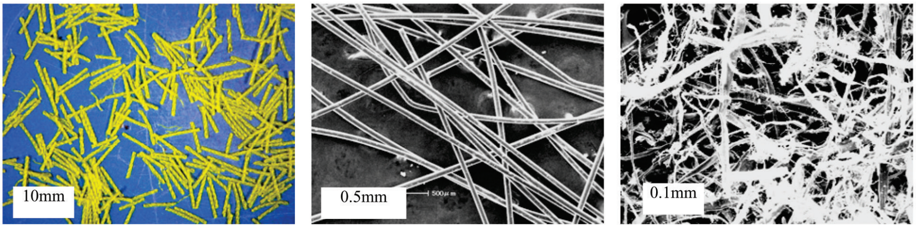
2.1 *Soil sample and short fibers*

Ariake clay was dredged at Fukuoka Prefecture in Japan and added small amount of cement, because it was difficult to transport it without treatment. The soil was used as a soil sample (soil particle density ρ_s = 2.604 g/cm^3, liquid limit w_L = 81.7%, plasticity index I_p = 46.8 and initial water content w_n = 52.3%).

Three kinds of short fibers are used and their shapes are shown in Photo 1. Nylon threads in place of waste fishing net were cut in length of 10 mm, commercially reproduced PET short fiber were used (length of 7.5 mm and diameter of 0.15 mm), and waste paper fiber was made by blending with water in food processor and breaking into flocculate.

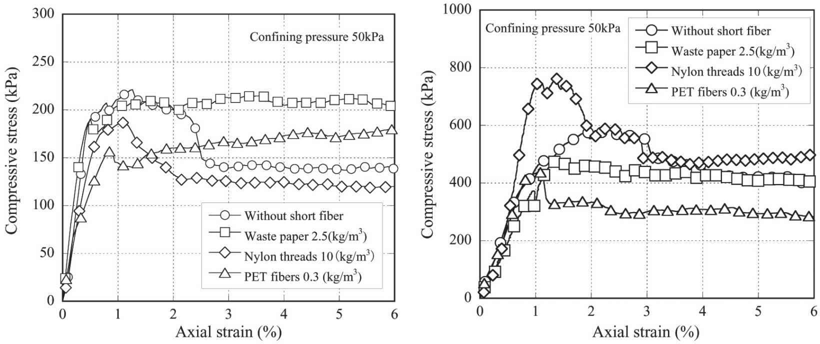
2.2 *Preparation of specimens and test conditions*

First of all, the Ariake clay is mixed with water, blast furnace cement and short fibers, and then this cement-treated soil slurry is remixed with air bubbles (foaming interfacial active agent). Flow value as an index of fluidity is more than 170 mm, cement content is 200 kg/m^3, and volumes of water and foaming agent were decided for obtaining wet density of 0.6 g/cm^3. Mixing condition of the specimens is presented in Table 1. Optimum fiber content is changed by shape, length



(a) Nylon threads (b) PET short fibers (SEM) (c) Waste paper (SEM)

Photo 1. Shape of used short fibers.



(a) Curing period of 7 days (b) Curing period of 28 days

Figure 1. Compressive stress and axial strain curves of air-formed lightweight soils with various types of short fibers.

Table 1. Mixing conditions of specimens.

Target wet density ρ_t(g/m^3)	Cement content (kg/m^3)	Type of short fiber	Fiber content (kg/m^3)
0.6	200	Without fiber	0
		Waste paper	2.5
		Nylon thread	10
		PET short fiber	0.3

and kind of short fiber, and therefore the fiber content was decided individually in consideration of kind of the material and preliminary experiment. Size of the specimen is in diameter of 50 mm and height of 100 mm, and these specimens were cured for 7 or 28 days in a humid room at the temperature of approximately 20°C. Triaxial compression tests (CU) were performed under confining pressure of 25, 50 and 75 kPa, and strain rate of 0.5%/min.

3 MECHANICAL PROPERTY OF AIR-FORMED SOILS WITH SHOT FIBERS

3.1 *Test results*

In order to clarify mechanical property of the air-formed lightweight soil under confining stress condition, triaxial compression test was performed. Figure 1 shows compressive stress and axial strain curves of the air-formed soils with short fibers under the confining pressure of 50 kPa. Compressive stress of the air-formed soil without short fiber decreases fairly after peak strength and the brittle behavior is observed. Although such brittle behavior is improved by mixing short fibers, the improvement effect depends on the kind of short fibers and curing period. It is observed that deformation-strength property of the air-formed soil changes from the brittle behavior to the ductile behavior by mixing waste paper or PET short fibers.

The triaxial test results on the air-formed soil are presented in Table 2. There is a scatter of wet density and the average wet density for each air-formed soil is in the range between 0.57 to 0.62 g/cm^3. Strength constants were decided at the condition of peak strength. There is a tendency that cohesion of the air-formed soil increases slightly by mixing short fibers. In some cases, appropriate frictional angle could not be obtained because of negative friction angle. Similar property has been confirmed for air-formed lightweight soil with very low density in the previous study (Watanabe and Kaino, 1999, Yasuhara, 2002.).

Relationship between the compressive strength and the wet density of air-formed soils is shown in Fig. 2. Compressive strength of the air-formed soil increases with increase in wet density for each curing condition. The improvement in the maximum compressive strength by mixing short fibers is not found at the same condition of wet density.

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Table 2. Test results of triaxial compression test on air-formed lightweight soils.

(a) Curing time 7 days

Short fiber	Content of fibers (kg/m^3)	Confining pressure (kPa)	Wet density ρ_t (g/cm^3)	Average wet density (g/cm^3)	Compressive strength, q_f (kPa)	Strain at failure, ε_f (%)	Cohesion c_{cu} (kPa)	Frictional angle, ϕ_{cu} (°)
Without fiber	0	25	0.618	0.605	201.5	1.0	54.84	22.93
		50	0.607		221.2	1.3		
		75	0.589		265.4	1.8		
Waste paper	2.5	25	0.615	0.618	197.3	1.9	60.11	19.45
		50	0.620		215.0	3.6		
		75	0.620		240.5	5.7		
Nylon thread	10	25	0.562	0.565	162.9	0.9	74.55	5.4
		50	0.569		186.5	1.1		
		75	0.564		173.3	0.7		
PET short fiber	0.3	25	0.560	0.567	174.2	2.9	67.24	10.51
		50	0.567		181.5	6.1		
		75	0.573		196.5	3.9		
(b) Curing time 28 days								
Without fiber	0	25	0.594	0.599	610.4	2.5	160.15	28.76
		50	0.592		588.1	2.3		
		75	0.611		703.1	1.5		
Waste paper	2.5	25	0.585	0.588	479.8	1.6	267.1	-
		50	0.591		478.9	1.4		
		75	0.588		471.0	1.5		
Nylon thread	10	25	0.610	0.607	666.4	1.1	161.41	34.38
		50	0.605		762.7	1.4		
		75	0.606		796.1	1.1		
PET short fiber	0.3	25	0.569	0.573	382.0	1.6	202.59	-
		50	0.578		436.5	1.1		
		75	0.571		380.9	1.0		

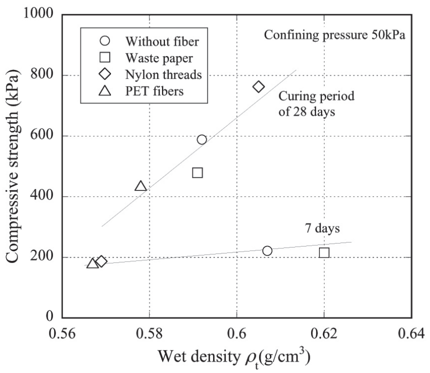
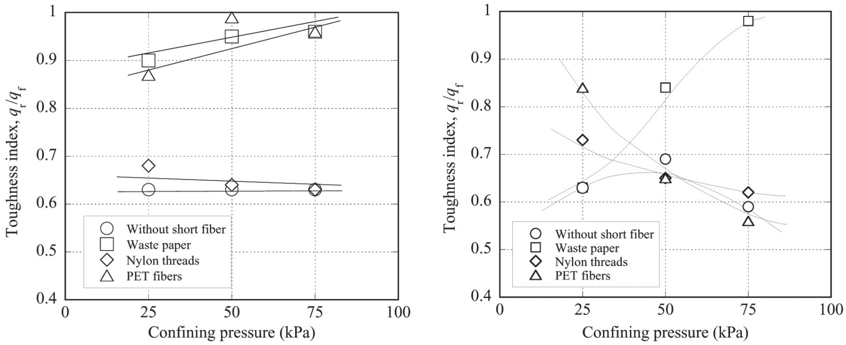


Figure 2. Relationship between compressive strength and we density of air-formed lightweight soils.

3.2 *Improvement in toughness*

As shown in Fig. 1, stress-strain behavior of the air-formed soil is improved by mixing short fibers. There are several indexes for evaluating toughness of material, for example, strain energy, ratio of residual and maximum strengths, and strain at failure. In this study, ratio of residual and maximum strengths is defined as toughness index, which is very simple and comprehensible expression. Relationship between the toughness index and the confining pressure of the air-formed soils is shown in Fig. 3. Obvious sliding surface could not observed for the specimens of the air-formed soils and non-uniform deformation was occurred at large strain. It is therefore that the compressive stress at axial strain of 6% is defined as residual strength herein. In Fig. 3 (a) for curing period of 7 days, the toughness index of the air-formed soils without short fibers or with nylon threads lies between 0.6 and 0.7. However, the toughness index of the air-formed soils with waste paper or PET short fibers is more than 0.9. It is considered that the toughness of the air-formed soil is improved by mixing very fine and short fibers. On the other hand, in Fig. 3 (b) for curing period of 28 days, the toughness index of the air-formed soils with waste paper or PET short fibers depends on confining pressure. This reason is not clear and further research is needed. However, the value of the toughness index for the air-formed soil mixed with any kind of short fibers is greater than that of the air-formed soil without short fibers. These results may be said that kind of short fiber should be selected in consideration of level of confining pressure for actual condition.



(a) Curing period of 7 days (b) Curing period of 28 days

Figure 3. Relationship between toughness index and con-fining pressure of air-formed lightweight soils.

Figure 4 shows change of the toughness index for curing period at the confining pressure of 50 kPa. In this condition, it is clear that the brittle behavior of the air-formed soil can be improved by mixing the waste paper fibers. As described above, the improvement effect depends on the kind of short fiber and confining pressure.

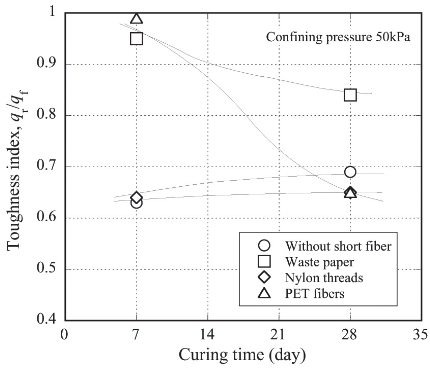


Figure 4. Change of toughness index of the air-formed soil for curring period.

4 CONCLUSIONS

The main conclusions obtained from this study are as follows:

- The deformation-strength property of the air-formed lightweight is improved by mixing short fibers and the effect for residual strength is much greater than the maximum strength.
- The improvement in toughness index (ratio of residual and maximum strengths) depends on the kind of short fibers and confining pressure.
- The air-formed lightweight soil with waste paper or PET short fibers is effective for both of utilization of the wastes and the improvement of brittle behavior.

REFERENCES

Omine, K. Ochiai, H., Yasufuku, N., Yamamoto, M. and Inoue, Y. (2001). “Improvement effect of composite geomaterial by utilization of plastic wastes”, Proc., International Symposium on Earth Reinforcement, pp. 111-116.

Takayama, E., Ochiai, H. Yasufuku, N. Omine, K. and Kobayashi, T. (2005). “Improvement effect on mechanical properties of cement-stabilized soils by mixing various types of short fibers”, JGS, No. 134, Proc., the symposium on cement-treated soil, pp. 336-338.

Watanabe, T. and Kaino, T. (1999). “Shear strength of foam composite lightweight soil”, Proc., 11 Asian Regional Conf. SMFE, pp. 47-48.

Yasuhara, K. (2002). “Recent Japanese experiences with lightweight geomaterials”, Proc., of International Workshop on Lightweight Geo-Materials, pp. 35-59.

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