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# TEMPERATURE EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH AND MICROSTRUCTURE OF FOAMED MIXTURE LIGHTWEIGHT SOIL CONTAINING FLAKED POLYETHYLENE TEREPHTHALATE (PET)

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## ABSTRACT

Lightweight soil technology has been widely used in construction projects to solve soft ground problems. Previous work, however, has shown that the maximum interior temperature of field test bodies reaches to about 90°C. On the other hand, industrial waste disposal is an increasing problem. PET (polyethylene terephthalate) waste is now generated in vast quantities to increased consumption of drinking water sold in PET bottles. Making effective use of PET waste as a ground material may help solve the problem of its disposal. This paper describes the effects of initial high temperature curing on unconfined compressive strength and the microstructure of foamed mixture lightweight soil containing PET flake. Increase in PET-cement ratio lessened the decrease in unconfined compressive strength with increasing initial temperature. This property makes PET flake useful as a construction material. However, unconfined compressive strength decreases with increasing initial temperature at all PET-cement ratios. Observations show that the microstructure of foamed mixture lightweight soil containing PET flake have noticeable cracks if samples are cured at 90°C for 1 day; the PET flake is not completely combined with the matrix. The formation of this microstructure is the main factor of the remarkable strength decrease based on initial high temperature curing.

**Key words:** internal structure, lightweight soil, recycling, temperature effect, unconfined compression strength (**IGC:** D6)

## INTRODUCTION

Lightweight soil technology is increasingly being accepted for the use in construction projects to solve soft ground problems. The most important advantages offered by this technology are reduced foundation soil improvement costs and reduced construction period, due to the reduced loading on the ground. Expanded Polystyrene (EPS) was adopted for road embankments on soft ground in Norway as early as 1972 (Frydenlund and Aaboe, 1993), and even then the use of EPS as an insulating material for frost protection purposes in road structures had proved satisfactory. The advantage of using EPS as a fill material was the substantial reduction of load on the subsoil offered by this material. When dry, EPS is nearly 1/100th the weight of other materials commonly used as light fill, but with strength characteristics that match the structural loads. This technique was introduced in Japan in 1986 (Yasuhara, 2002), after 22 years of experience using EPS in road structures.

The use of weight-reducing techniques for geomaterials started in Japan in 1974, by using styrofoam as a back-fill material to reduce the lateral earth pressure for quay walls (Nakase, 1974). This method was successful in reducing the vertical loads on soft ground as well as the lateral earth pressures on wall structures.

This technology is particularly useful in these cases: (i) reducing residual settlement of embankments constructed on soft ground, (ii) preventing differential settlement between approach embankments and structures, and preventing lateral flow of piled structures, (iii) preventing deformation during construction near housing, (iv) reducing the construction period, achieving nearly maintenance-free construction, and others (Miki, 2002). Field situations in which the techniques are potentially applicable are schematically described in Fig. 1.

Lightweight embanking methods are broadly classified into i) methods using lightweight materials such as expanded polystyrol (EPS) blocks and coal ashes, ii) methods using materials such as air-mixed lightweight soil and air-mixed beads, which are mixed with soils generated at the site, and iii) methods which use corrugat-

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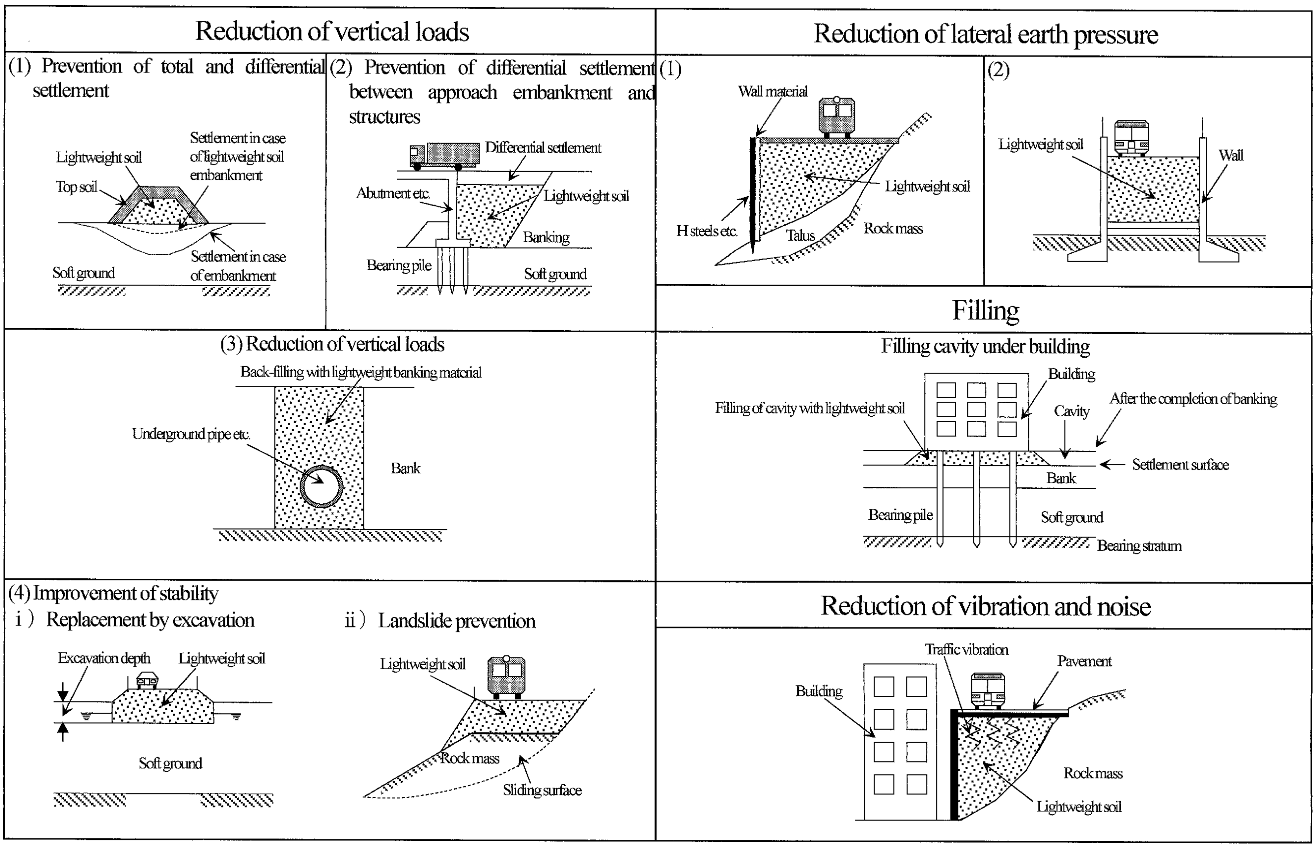



**Fig. 1. Several uses of the Foamed Cement Banking method (FCB method) (Kutara, 1994; Yasuhara et al., 2001)**

ed pipes and box culverts as parts of embankments to reduce their weight. The materials used for this method have a wide range of density, from EPS blocks to materials such as air-mixed lightweight soils and air-mixed beads whose density can be controlled freely. The method thus has various types and applications, and so it is necessary to select the method according to the purpose.

In expressway constructions, the Japan Highway Public Corporation uses Foamed Cement Banking method (hereafter called "FCB method") which is used at sites with special conditions, such as on soft ground, restricted terrain, reduction of construction cost, recycling of soils generated at the site, and to minimize disturbance of the natural environment (Sano et al., 2002).

More than 15 years have passed since the introduction of the FCB method, and the volume of such construction is increasing rapidly. Up until several years ago, the in-situ strength of FCB ground had hardly been tested, although the fundamental mechanical properties of foamed mixture lightweight soil were already known. Previous work has shown that the maximum temperature inside field test bodies changed with time in the range of 80–100°C, and that temperatures in the centers of the bodies were higher than those at the margins (Goto et al., 2002; Sano et al., 2002; Maekawa et al., 2003).

Maekawa et al. (2003) also reported that the unconfined compressive strength of core samples of foamed mixture lightweight soils did not reach the design strength. They then focused on the effects of temperature increase of fill induced by cement hydration on the unconfined compressive strength of foamed mixture lightweight soils at a construction site. Specimens were cured at temperatures of 20 to 100°C before unconfined compression testing, to investigate the effects of temperature increase due to cement hydration on the unconfined compressive strength of foamed mixture lightweight soils. Unconfined compressive strength decreases significantly between 20 and 100°C. The unconfined compressive strength of specimens cured for 28 days at high curing temperature (80 to 100°C) is about 25% that of those cured at 20°C. Finally, they found that re-evaluation of the design strength is necessary, and temperature management is important when foamed mixture lightweight soils are constructed. However, volume expansion of specimens cured at 80 to 100°C was observed in their experiment. It would therefore be preferable to check the strength deformation characteristics of specimens cured at 80 to 100°C where volume change occurs.

Industrial waste disposal is an increasing problem today. It is, therefore, becoming increasingly important for technology and engineering design to be utilized effectively for industrial waste disposal. PET (polyethylene terephtalate) bottles are now generated in vast quantities, due to increased consumption of drinking water sold in PET bottles. If PET bottles can be effectively utilized as a construction material, the problems of PET bottle disposal and shortage of natural resources for construction may be solved.

The purpose of this paper is to investigate the effects of initial high temperature curing on the unconfined compressive strength of foamed mixture lightweight soil containing PET bottle flake. Furthermore, the microstructures produced are to examine the factor of strength decrease due to initial high temperature curing.

## FOAMED CEMENT BANKING METHOD (FCB METHOD)

### *Outline and Features of FCB Method (Sano et al., 2002)*

The FCB method is one of the lightweight soil technologies in which foamed mixture lightweight soil is used as a geomaterial. Foamed mixture lightweight soil is produced from base soil (either generated at the site or purchased) by mixing with cement, water, and foaming agent. The fine mousse-like bubbles are stable in cement paste and mortar, and do not break during transportation by pressure pumping. It has been confirmed that the foamed mixture lightweight soil hardens, with the bubbles evenly distributed within the soil.

Wet density ($\rho_t = 0.5$ to $1.3\ \mathrm{Mg/m^3}$) and unconfined compressive strength ($q_u = 300\text{–}1000\ \mathrm{kN/m^2}$) of the soil can be controlled freely by changing the air content and the water cement ratio. The foamed mixture lightweight soil produced has various attributes, including lightweight, fluidity, self-sustainability after hardening, workability, and durability. The mix can be pressure-transported through pipes by pumps for up to 500 m without segregation, and the flow value can be controlled freely between 140 to 200 mm, according to transportation distance at the site. It can be transported long distances by pump and does not need spreading and compaction work. It can also fill narrow spaces, and enables rapid, low-noise, low-vibration execution of embankments. It is more resistant to ultraviolet rays, heat, and oil than organic high polymer materials.

Since the first application of the FCB method in an embankment of a construction road on a steep slope in the Sanyo Expressway project in 1988, the use of this method has increased year by year. Applications of the FCB method include embankments for road widening, embankments on soft ground, landslide areas and steep slopes, reduction of earth pressures behind structures, filling of confined sites where compaction work is difficult, and counterweight fills at tunnel portals.

### *Field Measurements of FCB Method*

Maekawa et al. (2003) investigated the mechanical properties of lightweight embankment. Two exploratory boreholes, named A and B, were made to depths ranging up to 8.5 m, in 28 days or more after embankment formation (*see* Fig. 2). Borehole A was 3 m inside the edge of the lightweight embankment, whereas borehole B was nearer the center, 9.45 m from the edge. Representative core samples were retrieved for examination and unconfined compression tests. Fig. 3(a) shows the variation of unconfined compressive strength with depth. Although the design was $1.0\ \mathrm{MN/m^2}$, unconfined compressive strength values ranged between 0.4 and $1.9\ \mathrm{MN/m^2}$, irrespective of depth. However, variation in dry density was comparatively small, with most values lying between 0.32 and $0.52\ \mathrm{Mg/m^3}$ (*see* Fig. 3(b)). The allowable error for wet density in the quality control criteria of the FCB method is $0.1\ \mathrm{Mg/m^3}$ or less (Japan Highway Public Corporation, 1996).

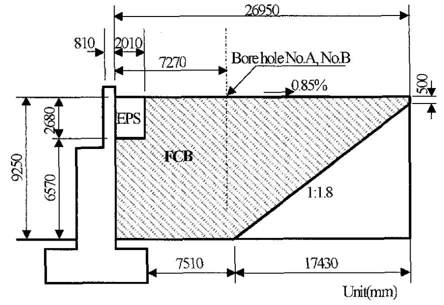



**Fig. 2. Cross section of lightweight soil embankment and positions of boreholes (Maekawa et al., 2003)**

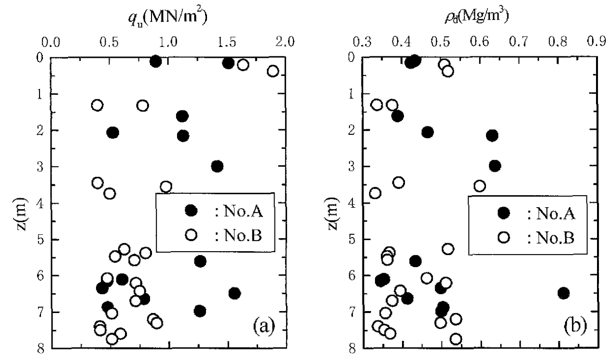
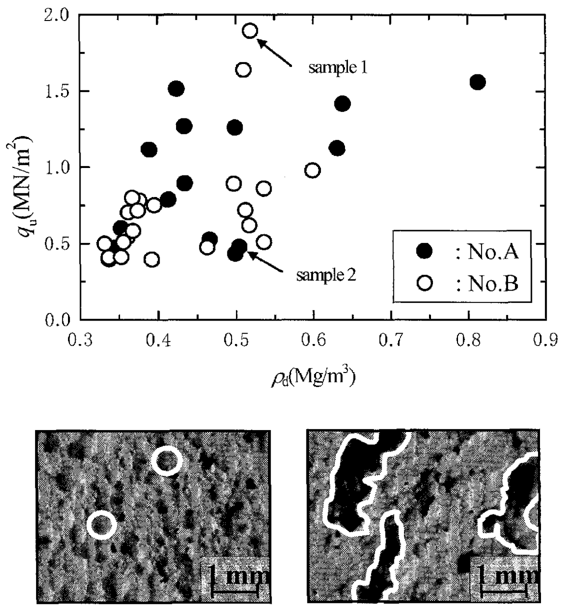



**Fig. 3. Variation of (a) unconfined compressive strength and (b) dry density with depth, from field measurements (Maekawa et al., 2003)**

A plot of unconfined compressive strength against dry density (Fig. 4(a)) shows no significant relationship existing between the two parameters, even though unconfined compressive strength of foamed mixture lightweight soil generally increases with increasing dry density based on curing (e.g., Kamei et al., 2002; Kamei and Matsuo, 2003). We assumed that the difference in unconfined compressive strength could be attributed to the differing microstructure of the lightweight soils, and so we investigated the microstructures using a stereo microscope. Figures 4(b) and (c) illustrate typical microstructures of foamed mixture lightweight ground; samples with these structures were observed in all places in the cores. The microstructure of sample 1, which has higher unconfined compressive strength, contained uniformly distributed and discontinuous small air bubbles. In contrast, the microstructure of sample 2 with lower unconfined compressive strength contained large, continuous, deformed air bubbles scattered throughout. The factors that produce these differing microstructures may be: (i) disappearance of air bubbles while the soil is poured and spread, (ii) downward movement of cement milk just after the soil was placed, (iii) heat of cement hydration while the soil is curing. Maekawa et al. (2003) focused on the heat generated by cement hydration while the soil was curing. Accordingly, the thermometry in FCB ground was measured in another project. To measure the in-situ internal temperature histories, thermocouple type temperature sensors were installed at points 0.05 m, 0.5 m, 1.0 m, 1.9 m and 5.4 m inside the edge of the lightweight embankment. The maximum temperature located at 0.05m was about 60°C. In contrast, the maximum temperature at the 5.4 m point, on which we focused, reached about 90°C, as shown in Fig. 5. After pouring and spreading of the foamed mixture lightweight soil, the internal temperature rose rapidly from 20 to 90 °C in the first day. The temperature subsequently fell slowly. It is notable that the internal temperature was very high (90°C) in the early curing period. Consequently, it is necessary to investigate the influence of high initial curing temperature on the unconfined compressive strength and structure of foamed mixture lightweight soils.




(b) sample 1 (c) sample 2

**Fig. 4. (a) Relationship between unconfined compressive strength and dry density from field measurements and (b) structure of sample 1 and (c) structure of sample 2**

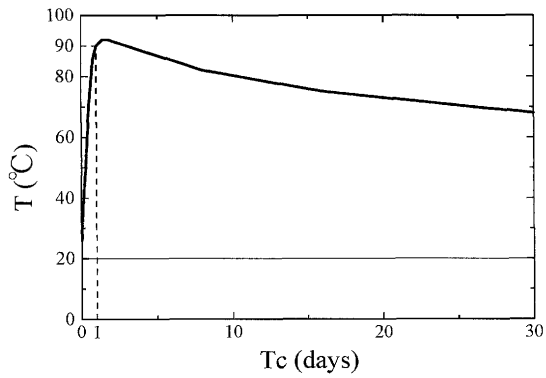



**Fig. 5. Internal temperature history from field measurement**

## SAMPLES AND TESTING PROGRAM

The mix proportions and quality control criteria of foamed mixture lightweight soils are shown in Table 1 (Japan Highway Public Corporation, 1996). Foamed mixture lightweight soil was prepared using blast furnace slag cement (B type), water, and synthetic surfactant foaming agent. Soils such as sand were not used in this study. About 10 specimens were prepared at a time to prevent quality from varying from specimen to specimen. Mixing the cement with water makes cement pastes with a mixer. Whipping the foaming agent with a whisk after dilution generates fine mousse-like bubbles. The foamed mixture lightweight soils are made by combining cement paste and the bubbles with a mixer. PET flake was then added to the lightweight soil and the mixed material was stirred, followed by thorough mixing to improve strength decrease due to initial high temperature curing. A sample of PET flake is shown in Fig. 6. The edges are sharp because the PET flake is cut. Quality control criteria of the PET flake are shown in Table 2, and a grading curve is shown in Fig. 7. Mixtures were prepared containing 0, 5, 10, 15, and 20% PET flake by mass relative to cement (P/C).

Air content, wet density and flow value of the mixed material were then measured. The air content of the mixed materials was calculated by measuring the volume before and after air bubbles were removed by mixing with ethanol to achieve constant volume (JHS A 313–1992).

**Table 1. Mix proportion and quality control criteria of foamed mixture lightweight soil**

| JH design mix proportion | Design unconfined compressive strength $q_u$ (MN/m$^2$) | Mix proportion | | | | | | Quality control criteria | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Water cement ratio $W/C$ | Cement $C$ (kg/m$^3$) | Foaming agent $m_1$ (kg/m$^3$) | Dilute water $m_2$ (kg/m$^3$) | Mixing water $m_3$ (kg/m$^3$) | Water $W^*$ (kg/m$^3$) | Wet density $\rho_t$ (Mg/m$^3$) | Flow value Flow (mm) | Air content $V_a$ (%) |
| K0-3 | 0.3 | 0.92 | 268 | 1.15 | 26.45 | 219 | 247 | 0.52±0.1 | 180±20 | 66.5±5 |
| K0-5 | 0.5 | 0.88 | 298 | 1.11 | 25.53 | 235 | 262 | 0.56±0.1 | | 64.0±5 |
| K0-10 | 1.0 | 0.82 | 353 | 1.03 | 23.69 | 264 | 289 | 0.64±0.1 | | 59.5±5 |

$(W^* = m_1 + m_2 + m_3)$

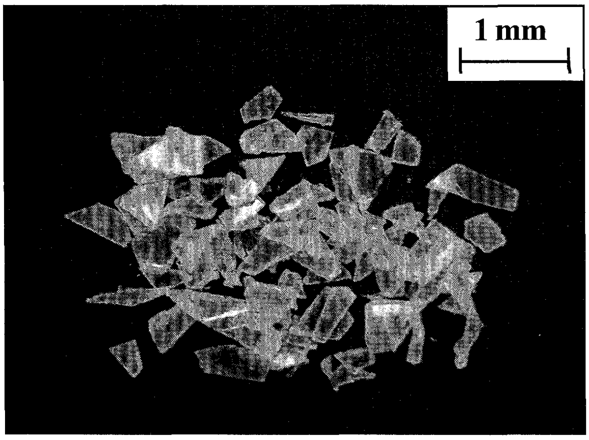



Fig. 6. PET flake

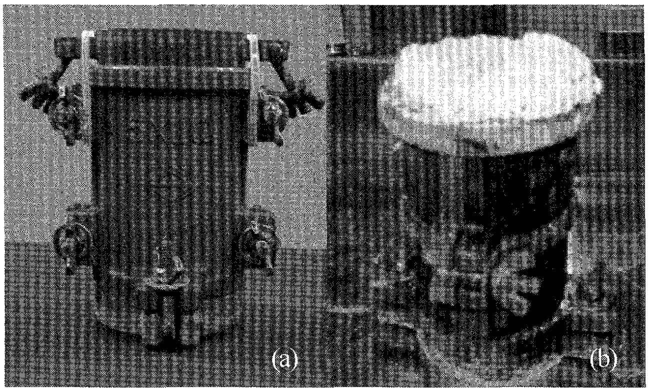



Fig. 8. Foamed mixture lightweight soil specimen cured at high initial temperature under (a) closed system conditions and (b) open system conditions

Table 2. Quality control criteria of PET flake

| Items | Standards |
|---|---|
| Specific gravity | 1.350 ~ 1.390 |
| Cut size | 8 mm$\phi$ screen |
| Water content | <0.6% |

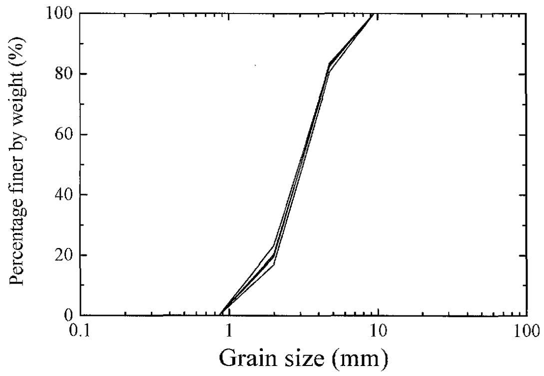



Fig. 7. Grading curve of PET flake

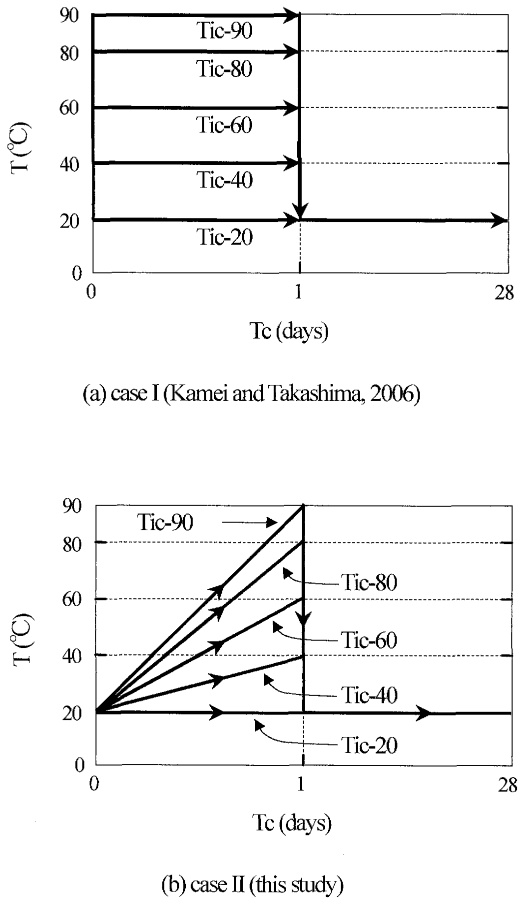



Fig. 9. Curing temperature history: (a) case I (Kamei and Takashima, 2006) and (b) case II (this study)

The flow value of a mixed material is an average of the maximum length and its width of flow from a cylinder with a height of 80 mm and a diameter of 80 mm (JHS A 313-1992).

The mixed material was put into a steel mold with diameter of 50 mm and height of 100 mm after quality control tests have been carried out. By putting a lid on the mold, the sample was held at constant volume during curing (Fig. 8(a)). By curing in an oven, the molded samples were subjected to two cases of curing temperature histories. The samples of case I (Kamei and Takashima, 2006) were subjected to prescribed initial curing temperatures ($T_{ic}$ = 20, 40, 60, 80, and 90°C) for 1 day, and then cured at 20°C for fixed periods (*see* Fig. 9). In case II, curing temperatures were slowly increased to reach prescribed initial curing temperature after 1 day, and then cured at 20°C for fixed periods (*see* Fig. 9). Although the curing temperature histories reflect oven temperature, the temperature in the samples would be comparable owing to their small size. All samples became self-supporting after the first day. We therefore judged that their internal structure was then completed, and that the curing temperature history after the first day was unlikely to affect their unconfined compressive strength and internal structure. Kamei et al. (2003) previously carried out unconfined compression tests of FCB specimens under several curing histories. For example, under the strict curing history of model test (1.8 m × 1.8 m × 2.18 m) in which temperature rose from 20 to 90°C in the first day, and subsequently fell to 20°C after 20 days; and under curing history in which temperatures were increased to reach prescribed initial curing temperature after 1 day, and then held at constant temperature (Maekawa et al., 2003). Unconfined compressive strength of samples cured at constant high temperature (80–100°C) after the first day was about 20% of those cured at 20°C. In contrast, unconfined compressive strength cured under the strict curing history was about 70% of those cured at 20°C. Unconfined compressive strengths in samples cured at initially high temperatures were lower than those cured at 20°C.

If samples were unconfined (hence permitting volume change) and were subjected to initial high curing temperatures (80 to 90°C in case I), the molded mixed materials expanded considerably, and overflowed the molds (Fig. 8(b)). In contrast, the volume scarcely changed at lower temperature conditions (less than 60°C).

Unconfined compression tests were conducted on several representative samples of foamed mixture lightweight soils with ages of 28 days. The tests followed standard procedure of the Japanese Geotechnical Society and employed a strain-controlled apparatus. The axial strain rate was 0.1%/min for unconfined compression tests. Three tests were carried out for each test conditions.

## EXPERIMENTAL RESULTS

Figure 10 shows the relationship between air content, wet density, flow value and PET-cement ratio just after mixing. All of the quality control values satisfy the quality control criteria of foamed mixture lightweight soil. Adding PET flake scarcely changed wet density and flow value, whereas, air content decreased linearly with increasing PET-cement ratio.

At first, we examined how initial high temperature curing influenced the unconfined compressive strength of foamed mixture lightweight soil without PET flake. The relationship between unconfined compressive strength cured under case II and initial curing temperature is shown in Fig. 11. Unconfined compressive strengths decreased linearly with increasing initial curing temperature. This tendency was also recognized in equivalent experiments, at all mix proportions.

The relationship between unconfined compressive strength ratio ($q_u/q_{u(\text{Tic-20})}$) and initial curing temperature is shown in Fig. 12. In case II, unconfined compressive strength ratio decreased linearly with increasing initial curing temperature, and unconfined compressive strengths cured at 90°C was half that of those cured at 20 °C. Although unconfined compressive strength ratio of case I specimens decreased gradually up to initial curing temperature of 60°C, as in case II, they fell significantly at initial curing temperature of 80°C or more. Consequently, for case I, unconfined compressive strengths of specimens cured at 90°C were about 20% of those cured at 20°C. High curing temperatures before specimens become self-supporting strongly influence unconfined

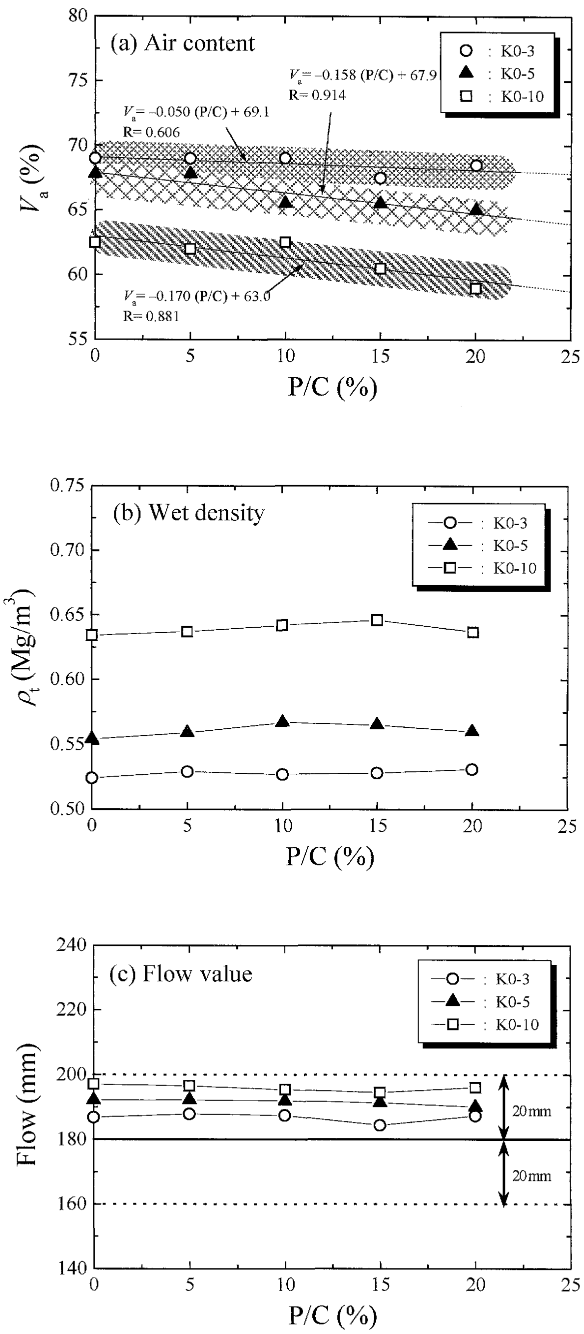



**Fig. 10. Results of quality control tests: (a) air content, (b) wet density and (c) flow value**

compressive strength.

Figure 13 shows the relationship between unconfined compressive strength of case II specimens and dry density. In K0–10, dry density values ranged between 0.430 and 0.475 Mg/m$^3$. These values satisfy quality control criteria at all mix proportions. The increase in dry density over the initial state would be attributed to microstructure development based on cement hydration. In contrast, the unconfined compressive strength values of K0–10 varied from 0.6 to 1.75 MN/m$^2$, even though the design was 1.0 MN/m$^2$. Variation in unconfined compressive strength was comparatively large at all mix proportions. Under initial high temperature curing, unconfined compressive strength of foamed mixture lightweight soil cannot be estimated from their dry density with any certainty because there is the case that they are remarkably different in unconfined compressive strength even if they are identical in dry density. Such variation in unconfined compressive strength agrees well with the results of actual unconfined compressive strength sampled from FCB ground. One of the reasons that the unconfined compressive strength cannot be predicted from dry density is the structural change induced by heating.

To investigate the internal structures in detail, typical microstructures of specimens cured under cases I and II were observed using a stereo microscope (Fig. 14). The microstructures in the sample cured at $T_{ic}=20°C$ contained uniformly distributed air bubbles. In contrast, the microstructure formed at $T_{ic}=60°C$ and 90°C contained larger air bubbles, many of which were connected by cracked matrix, thereby forming large cavities. This microstructure was observed regardless of temperature histories. The microstructures with large connected air bubbles were similar to the actual microstructures observed in FCB ground. Consequently, changing structure

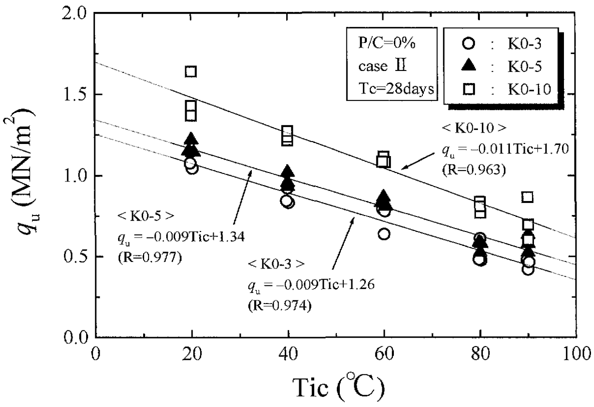



**Fig. 11. Typical relationship between unconfined compressive strength and initial curing temperature in specimens cured for 28 days (P/C = 0%, case II)**

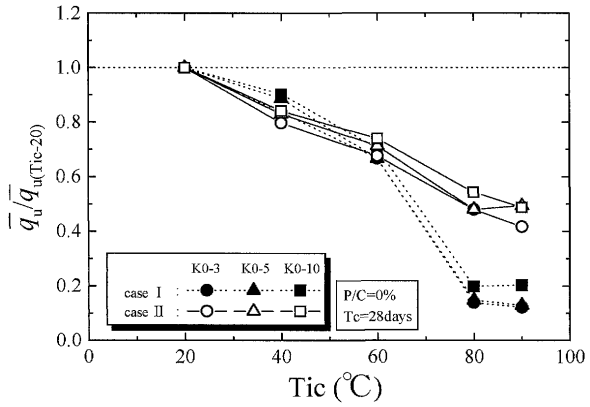



**Fig. 12. Relationship between unconfined compressive strength ratio and initial curing temperature in specimens cured for 28 days (P/C = 0%)**

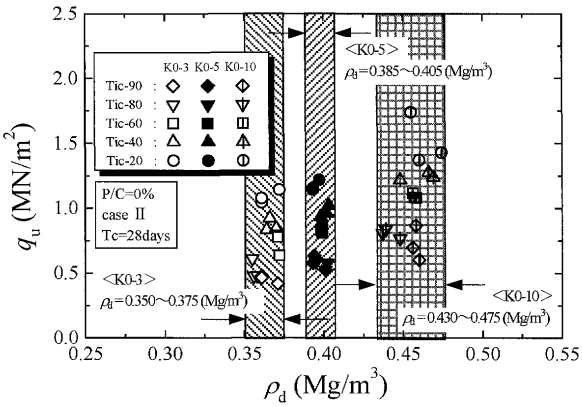



**Fig. 13. Relationship between unconfined compressive strength and dry density (P/C = 0%, case II)**

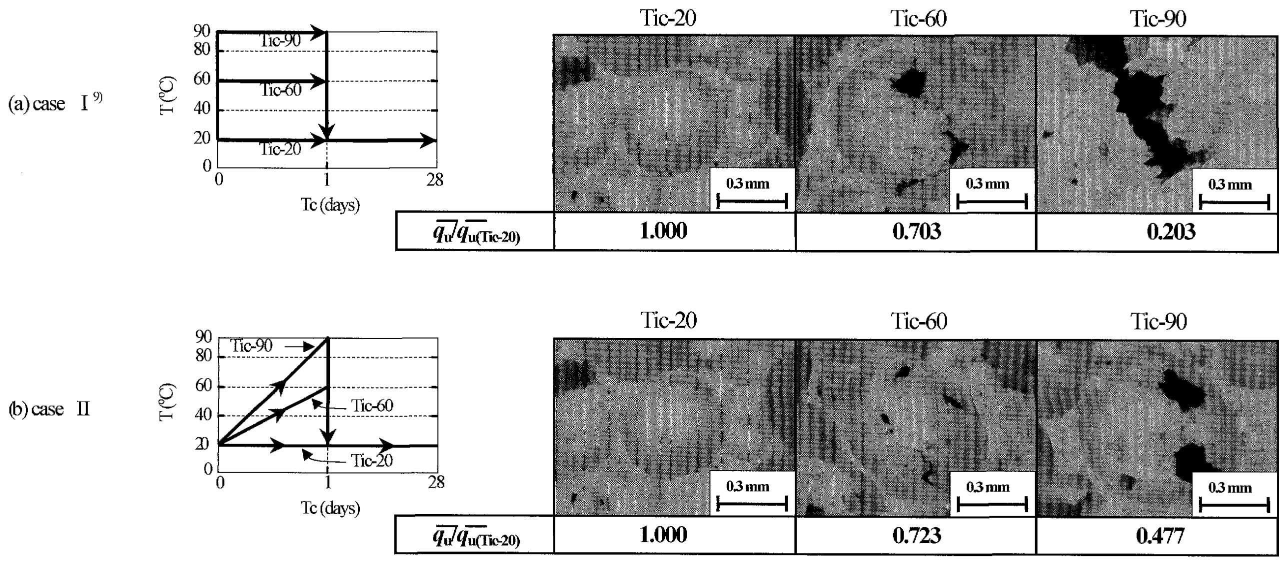



**Fig. 14. Typical microstructure of foamed mixture lightweight soil specimens cured at initial high temperature: (a) case I and (b) case II**

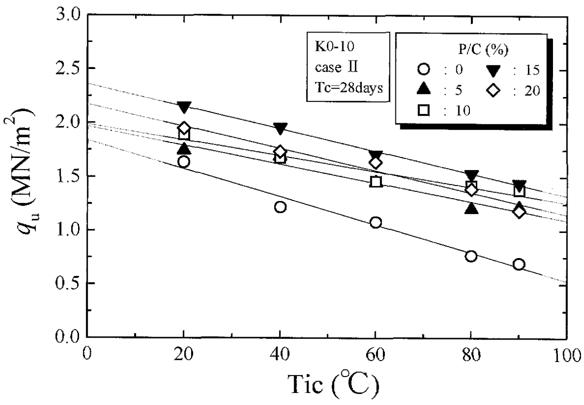


Fig. 15. Typical relationship between unconfined compressive strength and initial curing temperature in specimens cured for 28 days (K0-10, case II)

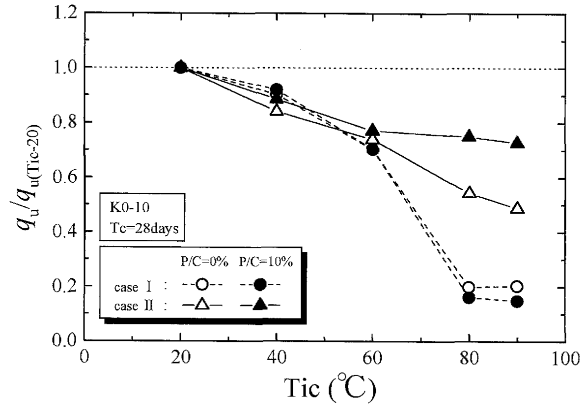


Fig. 16. Relationship between $q_u/q_{u(\mathrm{Tic\text{-}20})}$ and initial curing temperature in specimens cured for 28 days (K0-10, P/C = 0, 10%)

Table 3. Summary of equations for predicting unconfined compressive strength using P/C

| P/C (%) | Unconfined compressive strength | Coefficient of correlation |
|---|---|---|
| 0 | $q_u = -0.013$ Tic + 1.84 | 0.986 |
| 5 | $q_u = -0.009$ Tic + 1.97 | 0.974 |
| 10 | $q_u = -0.007$ Tic + 1.99 | 0.964 |
| 15 | $q_u = -0.010$ Tic + 2.36 | 0.998 |
| 20 | $q_u = -0.010$ Tic + 2.17 | 0.981 |

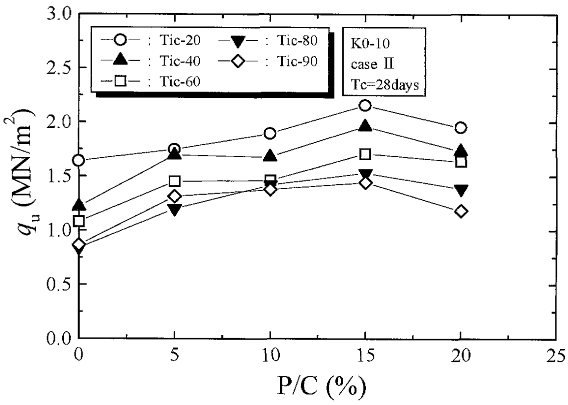


Fig. 17. Typical relationship between unconfined compressive strength and PET-cement ratio in specimens cured for 28 days (K0-10, case II)

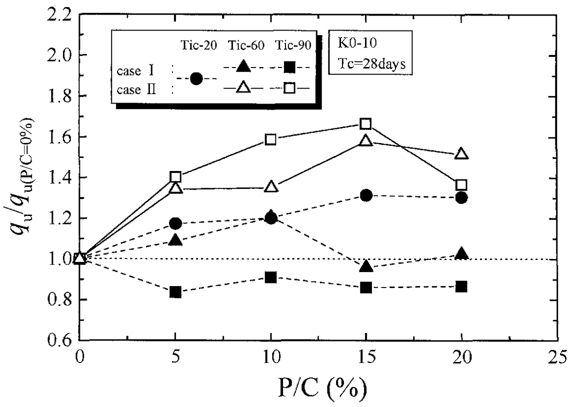


Fig. 18. Relationship between $q_u/q_{u(\mathrm{P/C=0\%})}$ and PET-cement ratio in specimens cured for 28 days (K0-10)

due to the heat generated by cement hydration would become a factor of variation in unconfined compressive strength of FCB ground. If FCB grounds are to be constructed, careful evaluation of the design strength is necessary, and strict management of the temperature and countermeasures against heat may be crucial.

Influence of the PET-cement ratio on unconfined compressive strength was investigated under the mix proportions of K0-10, because these proportions had little influence on the tendency for the strength to decrease with increasing initial curing temperature.

The typical relationship between unconfined compressive strength of case II and initial curing temperature is shown in Fig. 15. Unconfined compressive strength decreased linearly with increasing initial curing temperature at all PET-cement ratios. The values of the correlation coefficient obtained were remarkably high (all the values listed are over 0.96). Individual correlations are listed in Table 3. Unconfined compressive strength decreased with increasing initial curing temperature even if PET flake was added, but the increase of PET-cement ratio lessened the tendency for the strength to decrease with increasing initial curing temperature.

The relationship between unconfined compressive strength ratio ($q_u/q_{u(\mathrm{Tic\text{-}20})}$) and initial curing temperature is shown in Fig. 16. Under initial high temperature curing, unconfined compressive strength ratios were less than 1.0, irrespective of whether PET flake was added or not. Unconfined compressive strength was hardly improved by adding PET flake in case I. In contrast, in case II, the strength increase by adding PET flake was conspicuous at initial curing temperature of 80°C and above. Unconfined compressive strengths of specimens containing 10% PET flake and cured at 90°C remained at 70% of those cured at 20°C. In contrast, strength values of 90°C cured specimens lacking PET flake were less than half of those cured at 20°C. In case II, strength decrease

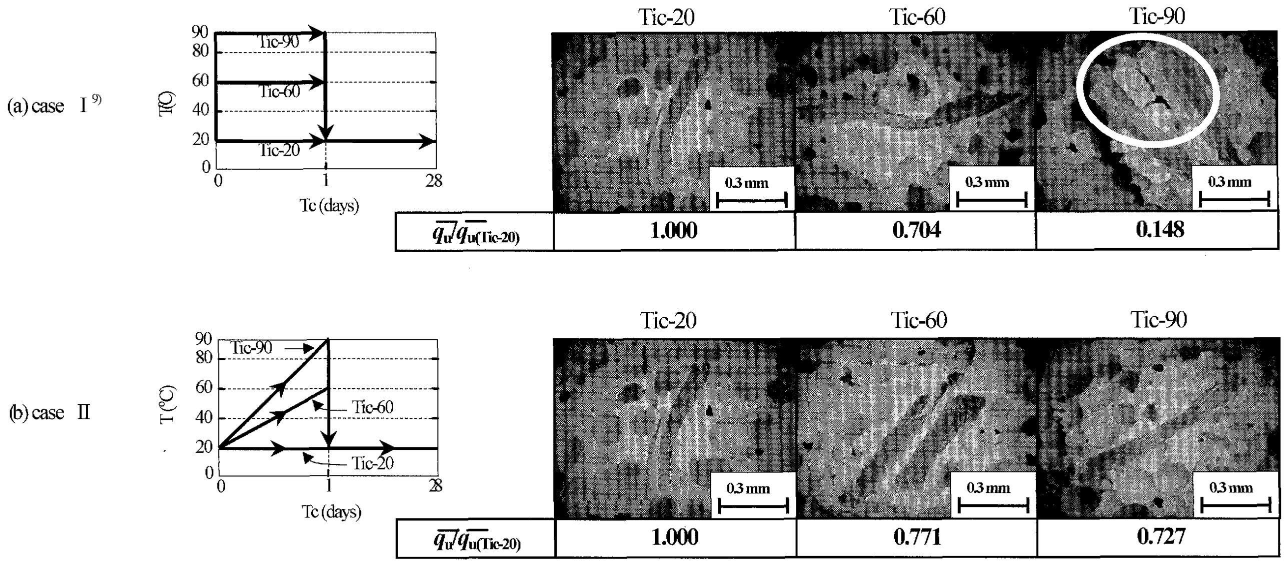



**Fig. 19. Typical microstructure of foamed mixture lightweight soil specimens containing PET flake cured at initial high temperature (K0–10, P/C = 10%): (a) case I and (b) case II**

is thus suppressed by adding flaky PET at the high initial curing temperature.

The relationship between case II unconfined compressive strength and PET-cement ratio is shown in Fig. 17. Adding PET flake increased unconfined compressive strengths at all the initial curing temperatures. Adding 15% PET flake increased unconfined compressive strength the most at all initial curing temperatures.

The relationship between unconfined compressive strength ratio ($q_u/q_{u(P/C=0\%)}$) and PET-cement ratio is shown in Fig. 18. Unconfined compressive strength was improved by 20% to 30% by adding PET flake when the temperature history was controlled. In contrast, the unconfined compressive strength of case II was greatly improved (30% to 70%) by adding PET flake, whereas the strength of case I was little improved.

The internal structure of foamed mixture lightweight soil containing PET flake was also investigated, because it influences the unconfined compressive strength, as supported by Fig. 13. Typical microstructures of specimens containing 10% PET flake were observed using a stereo microscope (Fig. 19). The microstructure cured at 20°C was strongly formed by combining PET flake with the matrix. For both case I and case II specimens with $T_{ic}$ = 60°C, the microstructures were also strongly formed, yielding microstructure like those cured at $T_{ic}$ = 20°C, although a few cracks were observed in the matrix. In contrast the case I specimen with $T_{ic}$ = 90°C, the microstructure contained noticeable cracks, and consequently the PET flake was not completely combined with the matrix. The difference of microstructures is the main factor of the remarkable strength decrease based on initial high temperature curing. Compared with Fig. 14, the size of air bubbles in the specimens containing PET flake were somewhat smaller, with diameter of about 0.2 mm. This structural change is caused by the destruction of large air bubbles by the sharp edges of the PET flake. Decrease in air content with increased PET-cement ratio, as shown in Fig. 10, is attributable to such a structural change.

## CONCLUSIONS

The following conclusions were reached:

(1) Increased PET-cement ratio lessened the tendency for decrease in strength with increasing initial curing temperature, although unconfined compressive strength decreases linearly with increasing initial curing temperature at all PET-cement ratios. If PET flake is mixed with FCB, it may thus be useful as a construction material.

(2) High curing temperatures before specimens become self-supporting strongly influence unconfined compressive strength.

(3) The microstructure of foamed mixture lightweight soil containing PET flake cured at an initial high temperature (case I) had noticeable cracks, and consequently the PET flake was not completely combined with the matrix. The formation of such microstructure is the main factor for the remarkable strength decrease based on initial high temperature curing.

It might therefore be necessary to reevaluate the design strength to meet the standard desired, and to manage temperature strictly during construction of FCB grounds. However, adding PET flake can lessen the strength decrease due to initial high temperature curing.

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