Fundamental Study on the Improved Soil Using Biodegradable Plastic and its Applicability as a Construction Material

生分解性プラスチックを用いた改良土の基礎的研究と建設資材としての適用性

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生分解性プラスチックを用いた改良土の力学的特性を確認するために、プラスチックの含有量と加熱時間を変化させて作製した改良土供試体について一軸圧縮試験を実施した。得られた一軸圧縮強さ（q_u）と変形係数（E_{50}）から，生分解性プラスチックを用いて砂を固化改良できることが確認できた。それらの特徴として，q_u はプラスチック含有量と加熱時間の両方に依存し，E_{50} はプラスチック含有量にのみ依存することが分かった。 また，セメント改良土との比較から，生分解性プラスチック改良土の強度はセメント改良土のそれよりも高いことが確認された。生分解性プラスチック改良土は適度な含有量と加熱時間を設定することで力学特性を変化させることが出来ることから、建設資材用途として有望であることを考察した。
キーワード：生分解性プラスチック，一軸圧縮強さ，変形係数，セメント改良土

Mechanical properties of improved sand using biodegradable plastic were examined by conducting a series of unconfined compression tests by changing the plastic content and the heating duration. It was found that the unconfined compressive strength (q_u) and the secant modulus (E_{50}) of sand can be improved using biodegradable plastics. q_u was dependent on both plastic content and the heating duration while E_{50} was only dependent on the plastic content. From the comparison with the results of cement treated sand, it was clarified that both q_u and E_{50} increased at a higher rate while increasing the plastic content. In terms of the mechanical properties, it concluded that the improved sand using biodegradable plastic performs well, as well as the cement treated sand and it is promising as an applicable construction material.
Key Words: Biodegradable plastic, Unconfined compressive strength, Secant modulus, Cement treated sand

1. INTRODUCTION

Recently, ecofriendly biodegradable plastics have been getting more attention as an emerging innovative material. Those are widely used in a variety of commercial applications such as packaging, disposable housewares, medical devices, agriculture and horticulture, and so on. However, in the construction industry, limited applications such as biodegradable resin concrete[1), 2)] and grout injection pipes made of biodegradable plastics [3)] have been reported. On the other hand, no examples in the application to the soil improvement have been reported up to date.

One of the possible applications of the improved soil using biodegradable plastic is to use for the constructions of temporary earth structures such as facing of the embankments, foundation of cranes, and so on. Generally, cement treated soil is widely used for these kinds of constructions and it is caused by additional cost at the removing process. Since biodegradable plastics are decomposed by microorganisms that cost can be reduced. In addition to that, when cement is used for soil improvement, there is a problem in hexavalent chromium elution depending on the soil type. Even though the use of biodegradable plastic in soil improvement reduces the environmental burden compared to the case where cement is used, there were no studies reported so far.

Therefore, in this study, fundamental experiments using unconfined compression tests on the improved soil with biodegradable plastic were conducted to understand the

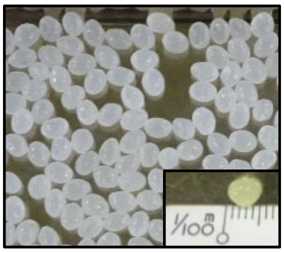


Fig.1. Biodegradable plastics

Table 1. Material properties

Heat Distortion Temperature (°C)	55
Melt Temperature (°C)	210
Particle density (g/cm^3)	1.24
Tensile Yield Strength (MPa)	60
Tensile Modulus (MPa)	3500

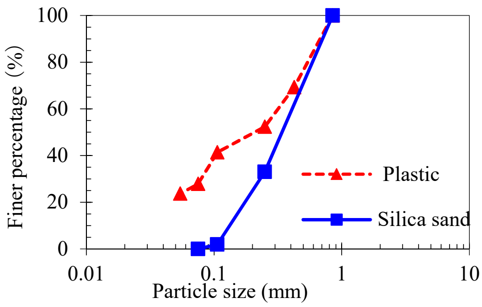


Fig.2. Particle size distribution

mechanical properties and the factors that are affecting them at the construction stage. Further, the obtained results were compared with the results of cement treated soil for discussing its applicability.

2. METHODOLOGY

2.1 MATERIAL

Polylactic acid (PLA) which is used in food packaging and foodservice ware application was used as the biodegradable plastic in this study. An image of plastic particles and their temperature and strength properties are shown in **Fig.1** and **Table 1** respectively. In this study, silica sand no.6(ρ_s = 2.65 g/cm^3, ρ_{dmax} = 1.54 g/cm^3, ρ_{dmin} = 1.26 g/cm^3) which was taken from Toki city, Gifu prefecture was used. Before mixing the plastics with sand, plastic was crushed into the finer particles. The obtained particle size distribution curves for both sand and the plastics are shown in **Fig.2**.

2.2 SPECIMEN PREPARATION METHOD AND EXPERIMENTAL PROCEDURE

Table 2. Experimental plan

Case	Plastic content (%)	Heating duration (min)
A	5 7 10 30	130
B	30	60 90 120 140 170 260

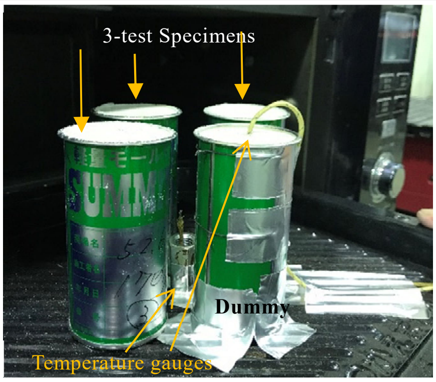


Fig.3. Specimen preparation method

Several sets of specimens were prepared under two cases as shown in **Table 2**. Case A was prepared to understand the behavior of mechanical properties when increasing the plastic content while Case B was to understand the effect of heating duration. It is important to study the behavior of mechanical properties against heating as it is possible to degrade at the construction stage before starting actual degradation due to decomposition.

In Case A, plastic contents were set as 5, 7, 10, and 30 % by dried weight of the sand while in Case B only 30 % was used. The determined plastics were mixed with sand in dry conditions. After making a uniform mixture, specimens with 50 mm in diameter and 100 mm in height were prepared inside steel molds by applying static compaction into three layers by setting the dry density around 1.4 g/cm^3. Four specimens were prepared under each plastic content.

Then those specimens were heated up to the melting point (210 °C) of the biodegradable plastic using a cooking oven. The temperature inside of a specimen and inside of the oven was measured by temperature gauges which were installed inside a dummy specimen and the oven as shown in **Fig.3**. In Case A, heating was stopped after 30 minutes from the time both temperature gauges reach 210 °C, which was after 130 minutes. In Case B heating durations were different for each set of specimens as 60, 90, 120, 140, 170, and 260 minutes. **Fig.4** shows the heating history for Case B. The temperature

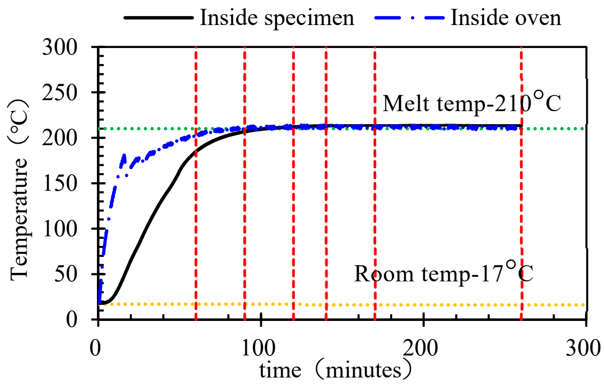


Fig.4. Heating procedure for Case B

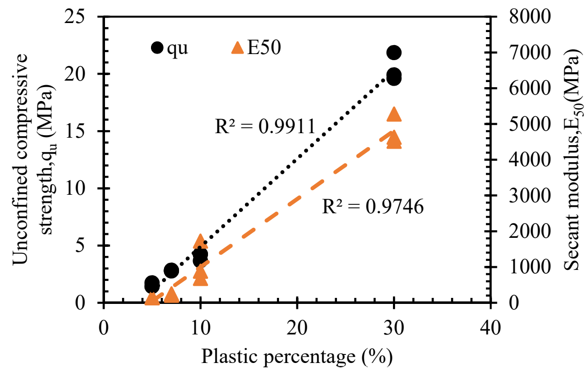
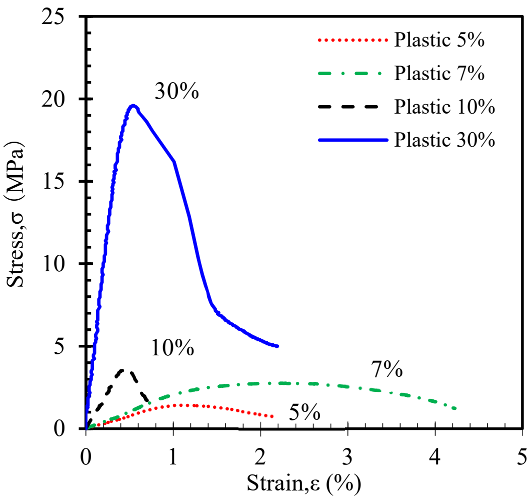


Fig.6. Relationship between unconfined compressive strength/secant modulus with plastic content-Case A



. **Fig.5.** Stress strain relationship-Case A

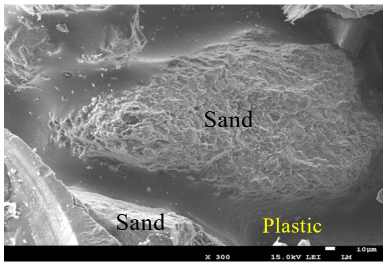


Fig.7. SEM image on sand + plastic 30%

inside the oven and the temperature inside the specimen gradually increased from room temperature. After heating to a relevant duration, the specimens were kept under room temperature for 24 hours. Then the steel molds were removed and measured the weight and the dimensions. Then the top of the specimen was leveled with gypsum before testing. Unconfined compression tests (JIS A 1216) were conducted on three specimens under each condition. Loading was applied with a rate of 1mm/min. The load and the displacement were measured periodically.

3. RESULTS AND DISCUSSION

3.1 EFFECT OF PLASTIC CONTENT

Fig.5 shows the obtained stress-strain relationships of the specimens which were tested under Case A. In here, the lowest unconfined compressive strength q_u was observed in plastic 5 % while the highest q_u as of 20 MPa was observed in the plastic content of 30 %. The relationships between the unconfined compressive strength q_u, secant modulus E_{50} and the plastic content are shown in **Fig.6**. It was observed that both q_u and E_{50} of improved sand increase when increasing the plastic content. In this improvement technique, plastic is the material that maintains the bonding between sand particles as observed in the SEM image of **Fig.7**. While increasing the plastic content it is possible to expect a maximum strength up to the yield strength of the plastic as of 60 MPa. However, in this study, the obtained q_u at 30% of plastic was one third of that value. Hence the relationship between q_u and the plastic content was considered as a linear relationship.

From the measurements, it was observed a reduction in the height of the specimens with plastic 30 % after heating by resulting in a higher density of 1.45 g/cm^3.This may also have a positive effect on the strength of those specimens.

3.2 EFFECT OF HEATING DURATION

The obtained stress-strain relationships for the specimens with 30 % of plastics under case B are shown in **Fig.8** following the heating duration. The q_u and the strain at failure were depended on the heating duration and the highest q_u was observed at 90 minutes as of 26.5 MPa. The obtained relationships between q_u, E_{50}, and the heating duration were plotted as in **Fig.9**. When the heating time was increased, q_u increased and then gradually decreased showing an optimum heating duration of 90 minutes. After heating 260 minutes q_u was dropped 40 % from the optimum q_u. In this case, the specimen was heated up to the melting temperature for a longer time. This might be caused to a thermal degradation which involved in changes of chemical composition. Some studies have been reported that this phenomenon leads to the appearance of different compounds such as lighter molecules and linear and cyclic oligomers[4]. To understand this effect further, the weight of the specimens before and after heating was measured. The obtained weight losses due to heating were 0.30, 0.37, 0.43, 0.63, 0.90, 1.27 g in accordance with ascending order of the heating duration. In addition to that clear change in the color of the specimen which was heated up to 260 minutes was observed as shown in **Fig. 10**. These results explained that there were some changes in the physical properties which were resulted by the thermal degradation of biodegradable plastic when heating longer duration. Similar observations were reported in previous studies[5].

However, in the case of E_{50}, clear changes against heating duration were not observed. The averaged E_{50} of all the cases was 4725 MPa as shown in **Fig. 9** which was higher than the modulus of plastic stated in **Table 1** as of 3500 MPa. This behavior was different from the expectation of the authors. However, no literature was found to support /against this result. Several studies were reported about the effect of heating rate on the mechanical properties and observed their reductions[5,6]. In this study, similar rate of heating was maintained in all the specimens. Hence it was considered that E_{50} might be depended only on the plastic content while independent from the heating duration. Further verifications are needed to be applied.

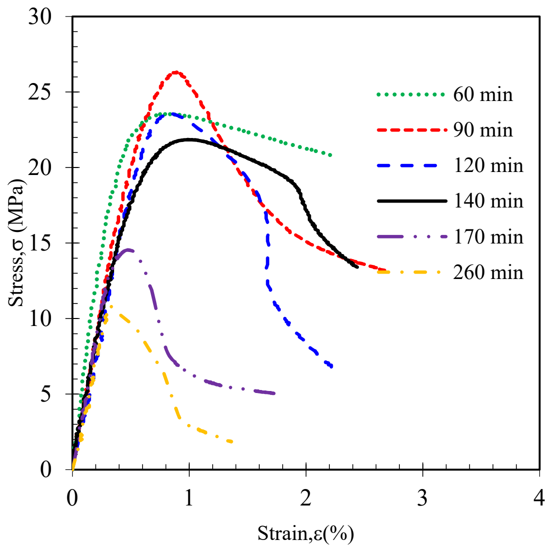


Fig.8. Stress strain relationship-Case B

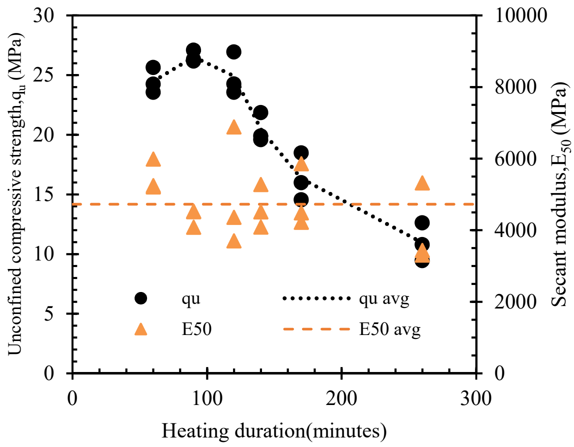


Fig.9. Relationship between unconfined compressive strength/secant modulus with plastic content-Case B

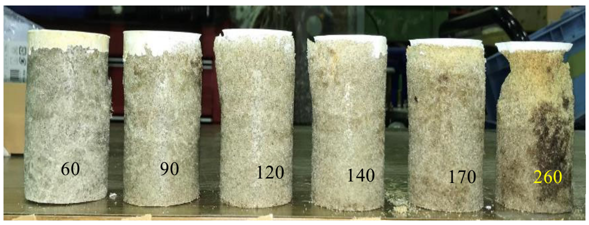


Fig.10. Photos of specimens after UCS test-Case B

4. APPLICABILITY AS A CONSTRUCTION MATERIAL

In this section, the applicability of the biodegradable plastic as a construction material was discussed by comparing the obtained results with cement treated silica sand. Here three sets of specimens were prepared by setting cement contents as 2, 4, and 8 % of the dry weight of the sand. These contents were different from the exact content of the plastic as they were originally prepared for another project. However, the minimum content of 2 % was decided as equal to the minimum cement content of 50 kg/m^3 which is recommended in the manual published by Japan cement association (JCA)[7].

Water content was set to 10.5 % of the dry weight of the sand. Specimens with a 50 mm in diameter and 100 mm in height were prepared using steel molds with a density of around 1.4-1.45 g/cm^3. The specimens were cured under constant temperature and humidity. Unconfined compressive strength tests were conducted in each set of specimens after 7 and 28 days of curing.

The obtained stress-strain relationships were plotted with the test results of improved sand using biodegradable plastics of 5, 7, and 10 % which were discussed in section 3.1 as shown in **Fig.11**. To compare the behavior of plastic treated soil, obtained q_u, and E_{50}, results were plotted against the binder contents as shown in **Fig.12 and 13** respectively. From those, it can be seen that the q_u and E_{50} of improved sands with both techniques increases linearly while increasing the binder content. The highest rate was observed from the improved sand using biodegradable plastics. In addition to that, q_u values obtained for plastic treated sand were higher than the cement treated sand in all the contents. On the other hand, E_{50} of plastic treated sand of 5 and 7 % were smaller than E_{50} of cement treated sand of 8 % after 28 days. However, it was observed that the same strength of 1.5 MPa can be achieved by using 5 % (125 kg/m^3) of plastic instead of using 8 % (200 kg/m^3) of cement and waiting for 28 days for curing. In such a case, improvement of sand with plastic is more effective in terms of strength and the time in the construction of temporary structures.

Generally, the strength of the cement treated soil enhance with time under controlled environmental conditions. When cement is used for the construction, the gained strength at the removal stage will be high. Generally, the strength of the soil which is easy to re-excavate is considered as 500kPa. When strength of improved soil exceeds this value, more machinery and labor cost need to be accounted. However, this additional cost can be reduced from the use of biodegradable plastic since it is decomposed by microorganisms[8].

From those results, it can be concluded that the improved sand using biodegradable plastic performs well, as well as the cement treated sand and it is suitable to use as a construction material. However, further studies on the applicability with different soils and the heating method at sites are needed to be conducted.

5. CONCLUSION

In this study, a series of unconfined compression tests were conducted on the improved sand with biodegradable plastic to understand the behavior of mechanical properties. The obtained results were compared with the results of cement treated sand for verifying its applicability as a construction material.

The findings can be summarized as follows.

1) Mechanical properties of sand can be improved using biodegradable plastic.
2) In improved sands with plastics;
    - Unconfined compressive strength (q_u) depends on the plastic content and the heating duration. Optimum strength can be achieved at the time in which temperature reaches the melting point of plastic. Heating for longer time cause in dropping of strength.
    - Secant modulus (E_{50}) depends only on the plastic

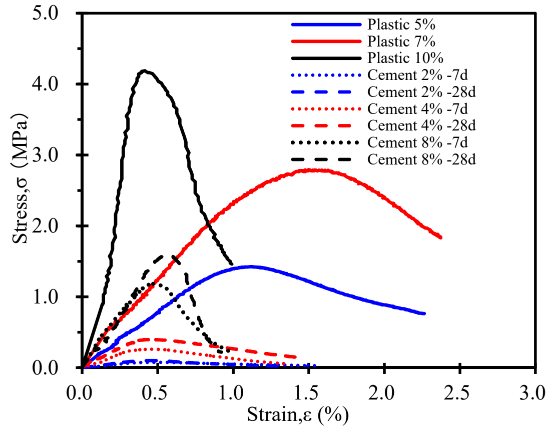


Fig. 11. Stress strain relationship-cement treated sand and improved sand using biodegradable plastics

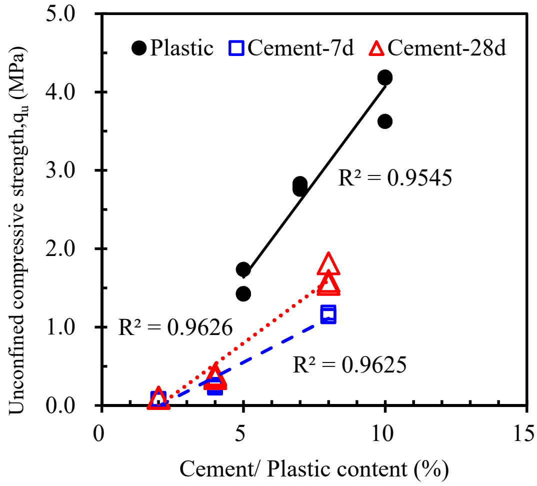


Fig. 12. Relationship between unconfined compressive strength and cement/plastic content

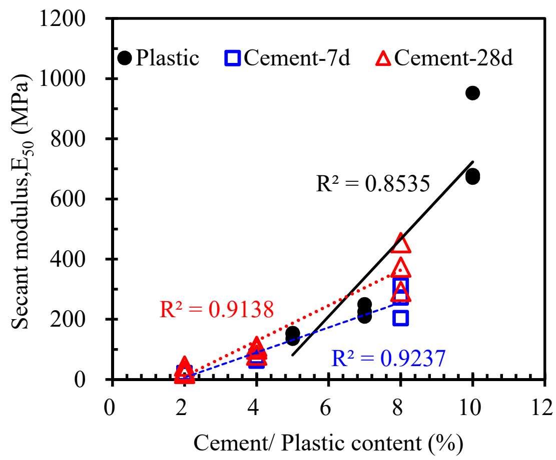


Fig. 13. Relationship between secant modulus and cement/plastic content

content when the specimens prepared under same heating rate.

3) In plastic treated soil both q_u and E_{50} increased at a higher rate compared to cement treated sand while increasing the plastic content.
4) The same strength achieved by cement treated sand after 28 days of curing can be achieved by the improved sand with biodegradable plastic using less plastic content and less time.

As a summary, it can be concluded that the improved sand using biodegradable plastic performs well, as well as the cement treated sand and it is promising as an applicable construction material.

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