INSOLUBLE TREATMENT OF POLLUTED SOIL WITH HEAVY METALS
BY MELTING AND SOLIDIFYING WASTE PLASTIC

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Abstract: Composite geomaterial using plastic waste was developed by melting and solidifying PET bottle with soil. The mechanical and chemical properties of solidification material was investigated by unconfined compression and leaching tests. Toyoura sand, decomposed granite soil and incineration bottom ash of munipal solid waste were used as soil sample. It is possible to make a solidification material with lightening and high strength by melting and mixing plastic waste. This method by melting solidification of plastic was also applied to polluted soil with heavy metals. It was confirmed from the leaching test that the plastic solidification is effective for the insoluble treatment of the polluted soil with heavy metals. Furthermore, utilization of plastic wastes was discussed from a viewpoint of life cycle and it was suggested that the reuse of plastic wastes as geomaterials is useful in extending the life cycle of plastic waste.

Keywords: Composite geomaterial, leaching test, lightening, life cycle, plastic waste, polluted soil, solidification, unconfined compressive strength

INTRODUCTION

Plastic wastes increase year by year and the disposal has become a serious problem in Japan. It is important to use these wastes effectively in the environmental point of view. The plastic wastes have been used by thermal recycling (reproduction fuel and heat collection) or material recycling. However, these recycles do not always enable because of transportation cost or capacity of facilities. As geotechnical utilization, it is considered to develop a new geomaterial by mixing soil with plastic wastes such as PET bottle or expanded polystyrene (EPS), which is chemically stable and lightening material. Several ideas for using plastic waste as composite geomaterials have been proposed by the authors (Ochiai et al., 2000).

First of all, solidification material is developed by melting and mixing plastic waste with soil. Granular sample and cylinder specimen are made by melting PET bottle under the temperature of 250~300°C and mixing with soil (Kitabayashi et al 2000). The unconfined compression test is performed on the plastic solidification material with Toyoura sand, decomposed granite soil or municipal solid waste (MSW) incineration bottom ash. In order to make clear the insoluble treatment of polluted soil with heavy metals, leaching test is also performed using an artificial polluted soil with metals of Cr, Cd and Pb. Furthermore, utilization of plastic wastes is discussed from a viewpoint of life cycle.

SOLIDIFICATION MATERIAL BY MELTING AND SOLIDIFYING PLASTIC WASTES

Various techniques concerning cementation or insoluble treatment for taking measures of polluted soil with heavy metal have been proposed. For saving the treatment cost, a simple and cheap way is expected. The proposed method is to melt plastic waste and mix it with polluted soil with heavy metal for insoluble treatment. PET bottle, which is thermoplastic material, is used in this study.

Soil samples and physical-chemical properties of solidification material

Decomposed granite soil, Toyoura sand and municipal solid waste (MSW) incineration bottom ash are used as sample. The particle size distribution curve of each sample is shown in Figure 1. The PET bottle was melted under 250~300°C using electric heater and mixed with the sample immediately in mixing weight ratios of 1 : 1 and 1 : 2 for the plastic and the soil sample. Density of the samples and the solidification material is summarized in Table 1. It is found that the lightening geomaterial is made by melting and mixing plastic waste. Chemical property of the solidification material is summarized in Table 2. Although original MSW incineration bottom ash indicates high value of pH (strong alkali), pH of granular
solidification material without crushing becomes the neutrality. Electric conductivity and approximation value of salt concentration decrease for plastic solidification.

![Figure 1 particle size distribution curve of each sample.](image)

Table 1 Density of samples and solidification materials.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Density of soil particle (g/cm³)</th>
<th>Density of solidification material (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PET bottle : soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 : 1</td>
</tr>
<tr>
<td>Decomposed granite soil</td>
<td>2.737</td>
<td>1.58</td>
</tr>
<tr>
<td>Toyoura sand</td>
<td>2.640</td>
<td>1.62</td>
</tr>
<tr>
<td>MSW bottom ash</td>
<td>2.608</td>
<td>1.33</td>
</tr>
<tr>
<td>PET bottle</td>
<td>1.40</td>
<td>-</td>
</tr>
</tbody>
</table>

* weight ratio

Table 2. Chemical property of solidification material.

<table>
<thead>
<tr>
<th>Samples</th>
<th>pH</th>
<th>Electric conductivity Ec (mS/cm)</th>
<th>Salt concentration C (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSW bottom ash</td>
<td>11.21</td>
<td>1.82</td>
<td>1165</td>
</tr>
<tr>
<td>Crushed solidification (less than 2mm)</td>
<td>10.49</td>
<td>1.50</td>
<td>960</td>
</tr>
<tr>
<td>Granular solidification (3~10mm)</td>
<td>8.29</td>
<td>0.27</td>
<td>173</td>
</tr>
</tbody>
</table>

*approximation value (C=640Ec)

Unconfined compression test

The unconfined compression test was performed on the solidified specimen with 3.5 mm in diameter and 90 mm in height. Compressive stress and axial strain curves of the solidification materials with mixing ratio of 1 : 1 are shown in Figure 2. Maximum stress of the solidification materials using Toyoura sand and decomposed granite soil is high comparing that of MSW bottom ash. The reason is considered that the density of solidification material using MSW bottom ash is less than those of Toyoura sand and decomposed granite soil as indicated in Table 1.
The relationship between unconfined compressive strength and void ratio is shown in Figure 3. It is found that the unconfined compressive strength of the solidification material decreases with increase of void ratio, and the values of the decomposed granite soil and Toyoura sand are much higher than that of MSW bottom ash. The reason is that a large amount of air is included in the solidification material when MSW bottom ash was mixed with melting plastic. However, the strengths of the decomposed granite soil and Toyoura standard sand are 10 ~ 25 MPa and that of MSW bottom ash is approximately 5 kPa, so that these solidification materials have high strength compared with usual soil. Thus, it is considered that the solidification material by melting and mixing plastic waste is useful as geomaterial in the point of strength property.

![Figure 2 Compressive stress and axial strain curves of the solidification materials.](image)

![Figure 3 Relationship between unconfined compressive strength and void ratio.](image)

**Leaching test**

Leaching test in Notification No. 46 of the Japan Environmental Agency is performed on the solidification material using Toyoura sand with heavy metals under different pH conditions for making clear the effect of insoluble treatment. The flow chart of leaching test is shown in Figure 4. The polluted soil
sample was made by adding heavy metals of Cr, Cd, and Pb in concentration of 10 mg/l into Toyoura sand. Mass of released metals in the leaching test is determined using ICP Mass Spectorometer. The granular solidification material with particle size of 5 ~ 19 mm, crushed solidification material of less than 2 mm and original polluted soil without treatment were used for the leaching test.

The results of the leaching test are shown in Figure 5 (a) ~ (c). As shown in Figure (a), total mass of released Cr for crushed solidification material of less than 2 mm becomes much smaller than that of polluted soil and the value is reduced at the level of 1/100 ~ 1/200 compared with the polluted soil. The value of released Cr for the granular solidification material in the particle size of 5 ~ 19 mm is reduced at the level of 1/200 ~ 1/1600. It is found from Figure (b) that total mass of released Cd for the polluted soil shows high value at the conditions of alkalinity and neutrality and it becomes small remarkably at the condition of acidity. Although the total mass of released Cd for the solidification materials was not detected for the reason of extremely small value, it is expected that the value lies under the environmental standard. On the other hand, it is clear from Figure (c) that total mass of released Pb shows high value at both conditions of alkalinity and acidity, and the value at the condition of neutrality becomes small. The concentration of released Pb for the crushed solidification material in the particle size of less than 2 mm becomes at the level of 1/10 ~ 1/100 compared with the polluted soil and that of the granular solidification material is reduced at the level of less than 1/100.

![Flow chart of leaching test on polluted soil](chart.png)

Figure 4 The flow chart of leaching test on polluted soil.
Figure 5 Relationship between total mass of released metals and pH.
Thus, the remarkable effect is seen for the insoluble treatment of polluted soil with heavy metal by plastic solidification and it is possible to make a new geomaterial with lightening and high strength. Plastic is chemically stable material with durability, so that this method is effective for the insoluble treatment of polluted soil. Furthermore, it is considered that a thermoplastic plastic such as PET bottle and expanded polystyrene (EPS) is useful for making plastic solidification material with high strength.

**UTILIZATION OF PLASTIC WASTES AS COMPOSITE GEOMATERIALS**

Various composite geomaterials using plastic waste have been developed from a point of reuse of waste materials. Table 3 summarizes characteristics of composite geomaterial using plastic wastes. The increase in shear strength can be expected by mixing heat compressed-crushed EPS with sandy soil (Yasuafuku et al, 2000). The unconfined compressive and tensile strengths of the cement-treated soil increase by mixing plastic pieces with slender and long shape and the brittle behavior is improved (Onine et al, 1996). Fishing net and vinyl sheet are available for improvement of strength of cement-treated soil with brittle behavior (Onine et al, 2001). It has been also confirmed that residual strength of sandy soil increases by mixing plastic pieces. Such utilization is an effective method in geotechnical engineering for using waste materials as reinforcement material.

Next, geotechnical utilization of plastic wastes is discussed in a viewpoint of a life cycle. Utilization as new composite geomaterials for embankment, back-fill or base coarse material is compared with general recycling method for plastic wastes. A plastic is regarded as a material ahead of strength and chemical stability, but it is seen as waste having difficulty with "a big calorific value" and "not disintegrate naturally". It is necessary to promote development of technology on utilization of plastic wastes still more in each field in order to extend a life of disposal landfill. When we evaluate utilization of wastes from a viewpoint of "reduction of environmental impact", the idea of life cycle assessment (LCA) from a product to disposal becomes important. Figure 6 shows a comparison of life cycles between the general recycling method and the utilization as geomaterials using plastic waste. For example, in the general recycling method, a waste plastic of PET bottles is reproduced by textiles of shirts, but in this case, these are disposed after several years and become a general waste material. In addition, frequency of recycling has been limited for deterioration of the material and a fall of quality when it is reused repeatedly. On the other hand, for the utilization as geomaterial, when the plastic waste is used as embankment or base coarse material, it can be used in a period for several decades because of being stable in ground for a long term. Therefore, the geotechnical reuse of plastic waste enables to extend a life cycle and it can be said that this method is effective for utilization of the waste.

**Table 3. Characteristics of composite geomaterials using plastic wastes.**

<table>
<thead>
<tr>
<th>Composite geomaterial</th>
<th>Plastic waste</th>
<th>Object of soil</th>
<th>Specimen</th>
<th>Improvement effect</th>
</tr>
</thead>
</table>
| • Mixture of sand and heat compressed-crushed EPS | Expanded polystyrene | Sandy soil | Mixing and compaction with crushed EPS | • Lightening  
• Increase of strength |
| • Cement-treated soil with plastic pieces | PET bottle  
Vinyl sheet  
Fishing net | Soft soil  
Dredged soil  
Sandy soil | Mixing slender pieces of plastic with soil | • Improvement of toughness  
• Increase of tensile and residual strengths |
| • Melting solidification material | PET bottle  
Expanded polystyrene | MSW bottom ash  
Fly ash  
Polluted soil | Solidification by heat melting and mixing with soil | • Lightening  
• High strength  
• Insoluble treatment of heavy metal |

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CONCLUSIONS

The main conclusions obtained from this study are as follows:

1) Solidification material with lightening and high strength was developed by melting and mixing PET bottle with soil. This is a composite geomaterial using plastic waste.

2) The release of metals for the solidification material in the particle size of 5–19mm is reduced at the level of 1/100 to 1/1000 compared with original polluted soil, and that of the crushed material in particle size less than 2mm becomes at the level of 1/10 to 1/100.

3) The plastic solidification is effective for the insoluble treatment of polluted soil with heavy metal.

4) The reuse of plastic wastes as geomaterials is useful in extending the life cycle comparing with previous recycle method of the plastic.

REFERENCES


