Techniques for the effective use of recycled asphalt pavement material as a civil engineering material

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ABSTRACT

From the viewpoint of the effective use of materials and environmental conservation, the recycling of waste materials generated at construction sites has been increasingly required. Asphalt pavement materials that are left after pavement repair are among such waste materials. Thus, for the purpose of effectively using waste asphalt, the applicability of recycled asphalt as a civil engineering material was examined by conducting laboratory tests and the trial construction of embankments. It was found that waste asphalt could be used in embankments and in frost blankets, and could be used for improving unsuitable soil.

Keywords: effective use, recycled asphalt, proceedings, civil engineering material

1 INTRODUCTION

The reuse and recycling of waste construction materials are actively promoted in civil engineering works in Japan. Sand and crushed materials produced by drilling prior to the repair of asphalt pavement are designated as “specified waste construction materials” pursuant to the Construction Material Recycling Act, and these materials should be recycled. Waste asphalt materials have been effectively used as base course materials after crushing, and as materials for hot-mix asphalt used for paving. In some regions, however, more waste asphalt is generated than can be effectively utilized, and it has been increasingly difficult for these regions to secure final disposal sites of surplus waste asphalt materials. The recycling and effective use of these materials will need to be maintained at a high level in the future, too. In light of the above, techniques for using waste asphalt materials for purposes other than paving are required. Thus, in an effort to expand the scope of application of waste asphalt, laboratory tests and the trial construction of full-scale embankments were conducted in order to examine techniques for using waste asphalt as a civil engineering material for embankments and frost blankets, and for improving unsuitable soil.

2 TESTING METHODS

Asphalt chunks and waste asphalt generated from pavement repair and drilling work are transported to asphalt recycling plants. After the impurities are removed, the waste asphalt is crushed and sorted for various purposes. This study addresses both asphalt materials produced at an asphalt recycling plant for reuse and asphalt materials cut from waste asphalt herein. Using these materials, laboratory tests and field test were conducted.

2.1 Laboratory tests

Laboratory tests were conducted to determine the basic physical properties of waste asphalt and to examine usability of such waste as a civil engineering material. With the aim of checking the usability of waste asphalt as a civil engineering material, basic physical properties such as density of soil particles, natural water content, particle size distribution, compaction curve, trafficability, and frost heave susceptibility were investigated according to the standards of the Japanese Geotechnical Society. To identify any hazardous substances that might be contained in waste asphalt and that might leach, we measured the elution of cadmium, lead, hexavalent chromium, arsenic, total mercury, selenium, boron, and fluorine, which are specified in the environmental quality standards.

The author considered that waste asphalt could be used for improving unsuitable soil, so we investigated the strength of compacted waste asphalt and compacted mixtures of waste asphalt and soil.

2.2 Field test construction

2.2.1 Construction method

At three places in Hokkaido (Tomakomai, Sapporo and Wakkanai), full-scale embankments were built on a
trial basis by using waste asphalt and a mixture of waste asphalt and soil. Each embankment had a height of 1.8 m, the crown width of 4.5 m ~ 5.0 m and a slope gradient of 1:1.5. The mixing of waste asphalt and soil, it was adjusted in Tomakomai and Sapporo by backhoe bucket, and in Wakkanai by rotary stabilizer. Waste asphalt or a mixture of waste asphalt and soil was spread and roller-compacted to make each embankment.

Each embankment was made up of 6 layers. Each layer was 30 cm thick, so the upper surface of the sixth layer was at a height of 180 cm.

In Tomakomai, the embankments were built on a 0.5 m-high foundation made of gravel with a diameter of 0~80 mm in order to avoid any effects of deformation due to subsidence induced ground deformation.

In Sapporo and Wakkanai, settlement plate was installed at the bottom of each embankment. In Tomakomai, one embankment was built without applying roller compaction.

Table 1 shows the physical properties of the waste asphalt materials tested. The soil particle density of the waste asphalt materials was 2.465~2.522 g/cm³. These values are lower than the particle density of typical soil in Japan: 2.6~2.8 g/cm³. The soil particle densities were low partly because asphalt components were adhered to the soil particles. The natural water content was 2.8~7.4 %. These values are much lower than the values of typical soil in Japan, and are close to the water content of rock.

Table 2 shows the physical properties of soil mixed with waste asphalt of soil used for mixing test and mixing conditions of soil and waste asphalt. shows the physical properties of soil mixed with waste asphalt. B is a high quality soil with a large cone index when compacted. However, A and C have a relatively high water content, the cone index when compacted is small. For this reason, the runnability of the construction machine cannot be ensured.

### Table 1. The basic physical properties of the waste asphalt.

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|------------|---|---|---|---|---|---|---|---|---|----|----|----|
| Occurrence place | Asphalt recycling plants | Construction site |
| Collection site | Sapporo | Wakanai | Chitose | Tomakomai | Yakumo | Tanno | Naka-gawa | Fuku-gawa |
| Soil particle density \( \rho_s \) (g/cm³) | 2.482 | 2.511 | 2.501 | 2.540 | 2.513 | 2.482 | 2.448 | 2.495 | 2.465 | 2.522 | 2.468 | 2.475 |
| Natural water content \( w_n \) (%) | 2.8 | 7.4 | 5.3 | 2.9 | 3.3 | 3.3 | 1.15 | 4.3 | 3.4 | 2.5 | 4.2 | 6.2 |
| Maximum particle size (mm) | 19 | 37.5 | 19 | 37.5 | 37.5 | - | 37.5 | 26.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| Grain size characteristics | 72.4 | 85.4 | 73.5 | 84.8 | 85.8 | - | 92.5 | 91.0 | 79.7 | 94.8 | 87.3 | 89.2 |
| 2mm (%) | 27.5 | 14.4 | 26.4 | 14.7 | 9.1 | - | 7.3 | 8.6 | 20.1 | 5.1 | 12.1 | 10.6 |
| 75-2mm (%) | 0.1 | 0.1 | 0.5 | 5.1 | - | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |
| Consistency limit | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. | N.P. |
| Ground material classification | GS | G-S | GS | G-S | G-FS | - | G-S | G-S | GS | G-S | G-S | G-S |
| Maximum dry density \( \rho_{dmax} \) (g/cm³) | 1.773 | 1.842 | 1.860 | 1.672 | 1.764 | 1.614 | - | 1.614 | 1.639 | 1.612 | - | 1.718 |
| Optimum moisture content \( w_{opt} \) (%) | 10.2 | 11.8 | 9.1 | 8.3 | 9.2 | 7.9 | - | 10.8 | 11.3 | 5.0 | - | 7.6 |
| Cone index \( q_c \) (kN/m²) | 1351 | >2000 | 1891 | >2000 | >2000 | 1420 | - | 2491 | 1478 | 1163 | - | >2000 |

### 2.2.2 Survey method

Ease of execution was investigated for each embankment, and sand replacement was used to measure
the density of each layer. For the purpose of checking the changes in the properties of each embankment over time, concrete plates were placed on the embankment crown, and the height of each embankment was measured at least once a month. To confirm the stability of each embankment by revealing the changes in embankment internal strength, the Swedish weight sounding test was conducted several times. Air temperatures were automatically measured at the beginning of each hour. In Tomakomai, embankments were cut at 3 years after construction so that the density could be measured by sand replacement and so that the impact acceleration could be measured as a way of understanding the strength.

3 TEST RESULTS

3.1 Laboratory test results

3.1.1 Physical properties of the waste asphalt

The particle size distribution curve for each waste asphalt type is shown in Figure 1. Although the maximum particle size varies slightly, all of the specimens contained a small fine-grained fraction and are classified as gravel. Waste asphalt has similar grain size characteristics.

![Fig. 1. Grain size characteristics.](image1)

Compaction curves for waste asphalt are shown in Figure 2. A compaction curve of common soil is also shown in Figure 2. Regarding typical soil, it has been reported that the optimum water content decreases and the compaction curve becomes sharper with increases in maximum dry density. In the waste asphalt materials, the maximum dry density was not very high, although the optimum water content was lower than that of typical soil. This result indicates that when waste asphalt is compacted by the application of adequate pressure, the waste asphalt can be used as a ground material that is lighter than conventional gravel. Waste asphalt has similar grain size characteristics.

![Fig. 2. Compaction curves.](image2)

Tests for assessing the frost heave susceptibility of the waste asphalt were conducted. The test results are shown in Table 3. The frost heave rate at 90% compaction was 0.024 mm/h. This value is as low as that for commercially available frost blankets. Only two specimens were used for testing, but because the waste asphalt materials used in this study had similar particle characteristics, all these materials had low frost-heave susceptibility and thus can be used for the frost blanket.

![Table 3. Frost heave of waste asphalt.](image3)

The cone index of the waste asphalt materials with natural water content was at least 1000 kN/m², which suggests that a small self-propelled scraper could operate on an embankment made of waste asphalt materials. Thus, it was concluded that when waste asphalt is adequately compacted, it can be used as a civil engineering material for embankments.

For all the waste asphalt materials used in this study, the amount of elution was measured for cadmium, lead, hexavalent chromium, arsenic, total mercury, selenium, boron, and fluorine. All measured values satisfied the environmental quality standards.

3.1.2 Strength of mixed soil of waste asphalt and unsuitable soil

Figure 3 shows the relationship between the ratio of the mass of waste asphalt to the mass of unsuitable soil and the cone index when mixing waste asphalt and unsuitable soil. The cone index increased by mixing waste asphalt. In the mixed materials, when the mixing amount (mass ratio) of waste asphalt becomes 1.33, the
cone index of the mixed soil exceeds 300 kN/m². When the mixing amount of waste asphalt increases further, the cone index became bigger. Waste asphalt is a material that can improve unsuitable soil.

![Cone Index Graph](image)

**Fig. 3. Relationship between the ratio of the mass of waste asphalt to the mass of unsuitable soil and the cone index.**

### 3.2 Field test construction

#### 3.2.1 Workability

At three construction sites, embankments were successfully built by spreading and roller-compacting waste asphalt or a mixture of waste asphalt and soil (Figure 4). Thus, waste asphalt is a civil engineering material that can be easily used for embankment construction.

![Construction Status](image)

**Fig. 4. Construction status**

#### 3.2.2 Embankment quality

The density of the fourth layer in each embankment immediately after roller-compaction of that layer is shown in Table 4. Excluding the embankment that did not roll, for every embankment, the degree of compaction exceeds the standard value of 90 %. This suggests that waste asphalt is a civil engineering material that can be roller-compact for construction.

![Density Table](image)

**Table 4. Dry density of embankment.**

| Embankment | Dry density (g/cm³) | Maximum dry density (g/cm³) | Degree of compaction (%) |
|------------|---------------------|----------------------------|--------------------------|
| 2          | 1.504               | 1.764                      | 85                       |
| 2 and B    | 1.663               | 1.632                      | 102                      |
| 4          | 1.842               | 1.658                      | 111                      |
| 4 and C    | 1.844               | 1.660                      | 115                      |
| 4:1        | 1.781               | 1.603                      | 111                      |
| 4:2        | 1.761               | 1.585                      | 111                      |
| 4:3        | 1.750               | 1.575                      | 111                      |
| 4:4        | 1.831               | 1.906                      | 96                       |
| 5          | 1.716               | 1.627                      | 106                      |
| 8:1        | 1.708               | 1.667                      | 103                      |
| 8:2        | 1.684               | 1.661                      | 101                      |
| 8:3        | 1.625               | 1.598                      | 102                      |

#### 3.2.3 Embankment displacement

The settlement of each embankment over time after construction is shown in Figure 5. Great settlement took place in the embankments built in Tomakomai in the first summer after construction. Settlement of the embankment built by using a mixture of waste asphalt and unsuitable soil was small. Embankment built by using waste asphalt without roller-compaction, exhibited the greatest settlement, followed by Embankment, to which roller-compaction had been applied. It can be concluded that both the mixing of soil and roller-compaction helped to reduce settlement. In Sapporo (Figure 5 B) and Wakkanai (Figure 5 C), settlement was also small at the embankments built with a mixture of waste asphalt and soil. The settlement was smaller in the embankments in Sapporo and Wakkanai than in the embankments in Tomakomai. This seems to have been caused by the fact that the degree of compaction was higher in the embankments in Sapporo and Wakkanai than in the embankments in Tomakomai. Among the three places, settlement was the smallest in Wakkanai, where air temperatures are cooler than in Sapporo and Tomakomai. Thus, to control the settlement of embankments built with waste asphalt, low temperatures and high degrees of compaction need to be ensured.

#### 3.2.4 Embankment strength versus elapsed time

The Swedish weight sounding test results are shown in Figure 6 for embankment in Tomakomai. Regarding the number of half-turns per meter, the depth from the crown increased over time after the construction of embankment. Embankment was built in winter, and the average monthly temperatures were -10~14 °C between late November and late May. Between late November,
when the embankment was built, and late May, temperatures were relatively low. Even during that period and also in the year after construction, the strength of embankment, built with waste asphalt, increased.

The degrees of compaction for the three years after the construction of the embankments in Tomakomai are shown in Figure 7. In embankment, the degree of compaction was roughly the same at different depths, although it was high at the depth of 30 cm from the crown. In embankments and, the degree of compaction was higher at greater depths.

It is likely that the lower part of the embankments
built by using waste asphalt is subject to great settlement from the load imposed by the upper part. The relationships between the impact acceleration and the depth from the crown are shown in Figure 8. The impact acceleration remained almost the same at different depths in Embankment A in Tomakomai. In Embankments B and C, the impact acceleration increased with increase in the depth from the crown. This result is consistent with the increase in the degree of compaction shown in Figure 7. Embankments built with waste asphalt differ from soil embankments in that settlement takes place in the former but not in the latter.

![Impact acceleration of compaction of embankment](image)

Fig. 8. Impact acceleration of compaction of embankment.

4 SUMMARY

A study was conducted with the aim of effectively utilizing waste asphalt as a civil engineering material. A series of tests revealed the following.

1. Waste asphalt can be used for constructing embankments. Although the soil particle density, natural water content, and other physical properties of waste asphalt differ from those of typical soil, waste asphalt can be roller-compacted to increase its density and strength. Because no hazardous substances are released from waste asphalt, it can be utilized as an embankment material.

2. The strength of a mixture of waste asphalt and unsuitable soil is higher than the strength of the soil alone, and the strength of the mixture increases over time. Thus, unsuitable soil can be improved by adding waste asphalt. Embankments built with improved soil are stable.

3. To control the settlement of embankments built with waste asphalt, it is necessary that the degree of compaction be high and that air temperatures be low.

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