INVESTIGATION OF MATERIAL SEPARATION OF MIXED CONSTRUCTION AND DEMOLITION WASTE BY SORTING PROCESS

Alonso Montero\textsuperscript{1*}, Yasumasa TOJO\textsuperscript{1}, Takayuki MATSUO\textsuperscript{1}, Toshihiko MATSUTO\textsuperscript{1}, Masato YAMADA\textsuperscript{2}, Hiroshi ASAKURA\textsuperscript{2}, and Yusaku ONO\textsuperscript{3}

\textsuperscript{1}Graduate school of Engineering, Hokkaido University
(N13, W8, Kita-ku, Sapporo, 060-8628, Japan)
\textsuperscript{2}National Institutes for Environmental Studies
(16-2 Onogawa, Tsukuba, Ibaraki, 305-8506 Japan)
\textsuperscript{3}Center for Environmental Science in Saitama
(914 Oaza-Kamitanadare, Kisai, Saitama, 347-0115 Japan)
\textsuperscript{*E-mail: amontero@eng.hokudai.ac.jp}

The final disposal ratio of mixed construction and demolition waste (MCDW) remains high in Japan, while progress has been made in the recycling of other construction and demolition waste. Sorting facilities are expected to play an important role in better management of MCDW. In this study, the feasibility of sorting facilities for the separation of material and of pretreatment for final disposal was investigated by conducting a batch experiment at a real operational facility. The material flow of each output fraction was determined based on the mass distribution and on analysis of the ignition loss and metal content. The separation of organic matter and ferrous metal achieved by the sorting process was excellent; almost 70% was separated out for recycling and did not go for disposal. Although the distribution ratios of heavy metals, such as Pb and Zn, sent to landfill were still high, their content little changed from the condition of the original mixed waste. The process of sorting MCDW achieved reduction of mass for disposal, reduction of the organic load directed to the landfill, and the diversion of iron from MCDW to recycling.

Key Words: Mixed Construction and Demolition waste, sorting process, recycling, material flow, heavy metals

1. INTRODUCTION

According to a survey conducted by the Japanese Ministry of Land, Infrastructure, and Transport\textsuperscript{10}, the recycling ratio of concrete and asphalt had risen to almost 98% by 2005 due to the steady application of on-site separation and to improvements in technology. On the other hand, of 2.9 million tonnes (Mt) of mixed construction and demolition waste (MCDW) generated, 2.1 Mt (72%) was disposed of, and the recycling rate was less than 15%. Reduction of waste placed into landfills is one of Japan’s targets for establishing a “sound material-cycle society.” Therefore, reducing the amounts of this type of waste sent to landfills is very important.

Based on the survey mentioned above, 45% of MCDW was transferred to treatment facilities where 32% was recycled, 29% was reduced, and 39% was disposed of. Thus, improving the recycling ratio at treatment facilities will be an important factor in reducing the disposal rate of MCDW in addition to the prevention of its direct disposal.

Treatment facilities should reduce the amounts of waste directed to the landfill by separating out the recyclable resources efficiently. However, as these facilities are operated by private companies, the type and quantity of material recovered are dependent on a number of market conditions, such as material costs, number of buyers, disposal standards, and disposal fees. Thus, understanding how the actual...
material cycle in such facilities would work for MCDW is essential.

The management of construction and demolition waste (CDW) is an important issue in many countries because of its enormous quantity2-8). However, insufficient useful data are available to examine material recovery from CDW because of the significant differences in conditions of CDW generation in each country depending on economic conditions, definition of CDW, scarcity of landfill space, and resource availability2-8). For example, the recycling rates of CDW in Germany and Ireland reach levels of almost 86%. However, the definition of CDW in these countries includes excavated soil9,10). The Netherlands also has a high recycling rate of 90%, but 92% of the application is road base11). The composition of MCDW is affected by these factors, and therefore management strategies and recycling efforts for MCDW differ from nation to nation and even from site to site12-14). Thus, material recovery rates of MCDW treatment facilities are difficult to compare.

Information on the material recovery rate in MCDW sorting facilities is extremely limited. The California Integrated Waste Management Board does publish the recycling rates of some recycling facilities that treat MCDW15). However, these rates represent the overall recycling rates of the facilities, and do not specify whether these facilities accept source-separated material or if some recyclables are removed from the mixed waste beforehand.

On the other hand, the characteristics of MCDW generated in Japan, where CDW recycling is a high priority, are different because the recyclable materials are thoroughly eliminated beforehand, leaving only MCDW. Under such conditions, the function of the MCDW treatment facility is not only material recovery but also pretreatment to reduce the load entering the landfill. As the latter function is key, the methods by which organic matter or metallic elements are diverted from landfill are of great importance.

This study was performed to examine the material flow of an MCDW treatment facility. This report also discusses the effectiveness of the process for material separation and how the characteristics of the separated material compare with the original waste.

Brunner and Stampfli16) used a similar approach in an investigation of material flow of a full-scale construction waste sorting plant and reported the characteristics of four output fractions (less than 80 mm, light, heavy, and metal) and the transfer coefficients of various elements. Their research boundary was the whole process of the plant, including the presorting of recyclables. The main focus of the present study, however, was the sorting process of MCDW remnants from which most recyclable material had already been removed in presorting. This is because how the quality of landfilled material can be improved is an important consideration in this study.

A batch experiment was conducted at an actual operational facility, and the output mass of each material was measured. The samples obtained from the batch experiment were then analyzed to determine their organic matter and heavy metal contents. The distribution ratios of various elements were calculated using the mass flow data and analytical results. Finally, the performance of material separation and the quality of the separated fraction sent to the landfill were evaluated.

2. METHODS

This section describes the treatment facility, the details of the batch experiment, the analytical procedure used for the samples, and the method of calculating the distribution ratio.

1) Facility description

The investigation was performed at a facility located in the Kanto area in Eastern Japan. This was a carefully selected typical treatment facility that accepts CDW generated in the area. The amount of CDW delivered to the facility each day is almost 1000 m³. After weighing and inspection on entrance to the facility, the waste is accepted for treatment. Large recyclable items, such as iron frames, reinforcing bars, wood panels, recyclable plastics, and gypsum board, are first removed from the waste manually or using heavy equipment. Then, the remaining MCDW, which is in a completely mixed state and accounts for nearly 23% of the initial volume, is subjected to the sorting process shown in Fig. 1. This sorting process was the research focus of this study.

The process flow is as follows. The input MCDW first goes to a 30-mm screen. In this study, the process line treating waste smaller than 30 mm that passes through the screen is called the non-shredded line (NSL), and the process line with the shredder treating waste larger than 30 mm is called the shredded line (SL). The material under 30 mm goes through a magnetic separator where ferrous metals (denoted as NSL-F) are removed, and then the fine fraction (NSL-A) is separated by an 8-mm screen. The remainder in the range 8-30 mm is segregated by the air classifier into light and heavy (NSL-B). The light fraction is sent to the shredder. The
Fig. 1 Flow diagram of sorting process investigated in this study.

material that was over 30 mm at the first screening is passed to a hand-sorting operation where recyclables, including metal M(F), wood M(W), paper M(Pa), plastic M(P1), and concrete M(Co), are removed manually. The remainder is then sent to a high-speed shredder. Shredded material goes to a trommel that separates out any material over 100 mm (SL-E). From the material under 100 mm, the fine fraction (SL-A) is first separated by an 8-mm screen. The material in the range 8–100 mm goes to a 30-mm screen to be separated into 8–30 and 30–100 mm (SL-D) fractions. The material under 30 mm in size is further separated by an air classifier into heavy (SL-B) and light (SL-C). The light components in the SL-D are separated from the heavy components by air classification and liquid separation. There are three magnetic separators in the SL but the separated ferrous metals are combined and discharged from a single point (SL-F). This sorting process is a typical process that is commonly used in this type of treatment facility as described by Hendriks and Pietersen17).

As indicated in Fig. 1, the destination of each separated material is as follows. NSL-A, SL-A, and SL-C are disposed of in the landfill. NSL-B and SL-B are utilized as aggregate in concrete. After SL-D is separated, the floating material is sent to the incinerator and the remainder goes to the landfill.

SL-E is sent to the incinerator or sold as alternative fuel depending on its quality. Ferrous metals are sold as scrap iron.

(2) Batch experiment details

Before conducting the experiment, the flow of waste entering the process was halted and all remaining material inside the process was processed and discharged. Every location or output bunker/container was cleaned, and plastic sheeting or plastic buckets were installed to accept all further output material.

A sample of 1740 kg (3.22 m³) of MCDW was prepared for the experiment. It was selected by the facility personnel to ensure that it represented typical waste treated by the process.

The process line was restarted and the waste was introduced into the process all at once. After confirming that all the material had been processed completely, the material accumulated at each output was weighed. The collection points were NSL-A, NSL-B, NSL-F, SL-A, SL-B, SL-C, SL-D, SL-E, SL-F, and each material separated by hand-sorting (M); these are indicated by gray shaded boxes in Fig. 1. Although SL-D is processed further, it was collected before it entered the post-processing of air classification and liquid separation because post-processing is not directly connected with the main processing line.
Immediately after weighing each output, a sample of 5–10 kg was obtained from each of seven outputs (NSL-A, NSL-B, SL-A, SL-B, SL-C, SL-D, and SL-E) by the quarter sampling method. Ferrous metals of both lines and recyclables separated by hand-sorting were weighed but were not sampled because they can be considered as unit components.

(3) Analytical procedure

The output samples were analyzed for water content, physical composition, ignition loss (IL), carbon/hydrogen/nitrogen (CHN), total organic carbon (TOC), and metal content (Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Pb, Sb, and Zn). The analysis procedures were as follows:

a) Water content

Samples of 100 g of each output sample were dried at 105°C for 24 h. The water content was determined by dividing its weight loss by the initial weight.

b) Physical composition

A portion of 250 g of each sample was used for the analysis. First, the sample was sieved with a 2-mm screen. For the fraction greater than 2 mm, the material was visually classified as concrete, material such as wall or gypsum board, metal, glass, wood, paper, and plastic. It was possible to classify SL-D and SL-E samples further because they are composed of relatively large components. These were divided into 14 categories such as paper, film plastic, foam, textiles, wood, concrete, gypsum board, wall material, hard plastics, rubber, glass, metal, electrical wire, and stone.

c) IL

A portion of 10 g of each dried sample was maintained at 600°C for 3 h. The IL was determined by dividing the weight loss by the initial dried weight.

d) CHN

All samples except SL-D and SL-E were tested at the Center for Instrumental Analysis of Hokkaido University.

e) TOC

A TOC analyzer (TOC-V; Shimadzu Corp.) combined with an SSM-5000A solid sample combustion unit was used in the following procedure. The dry sample was shredded to make it homogeneous and then a portion of 0.5 g was used for testing. Each analytical sample was duplicated because separate analyses for total carbon (TC) and inorganic carbon (IC) were necessary to determine TOC. One prepared sample was placed in a ceramic boat and introduced into the combustion unit. Carbon dioxide produced by combustion was measured using an infrared gas analyzer to determine the TC.

Pure glucose was used to obtain a TC calibration curve. The other sample was also placed in a sample boat and oxidized by concentrated phosphoric acid. The carbon dioxide generated was analyzed by the infrared analyzer to determine the IC. Sodium carbonate and sodium bicarbonate were used to obtain an IC calibration curve. Finally, the TOC of the sample was calculated by subtracting IC from TC.

f) Metal content

A portion of 10 g of each dried sample was digested with aqua regia. After filtering through 5B filter paper, the resulting liquid was analyzed by inductively coupled plasmography (ICPE-9000; Shimadzu Corp.).

(4) Distribution ratio calculation

This study focused on the distributions of organic matter and heavy metals. The organic carbon content such as TOC would be a better way of evaluating the distribution of organic matter. However, TOC analyses for SL-D and SL-E were not possible because of their size. Therefore, IL was used as a substitute. All 13 metal contents were used for calculation of metal distribution.

As shown in Eq. (1), the mass of element j distributed in material i \( m_{ij} \) was calculated by multiplying the mass of material i \( M_i \) and content of element j in material i \( C_{ij} \). Here, the mass of material i was corrected to the dry mass using the water content.

\[
m_{ij} = M_i \cdot C_{ij}
\]

The distribution ratio of element j into material i \( r_{ij} \) was calculated by dividing the mass of element j in material i by the total mass of element j, which was obtained by summing the mass of element j in each material, as shown in Eq. (2).

\[
r_{ij} = m_{ij} / \sum_{i=1}^{n} m_{ij}
\]

The data of previous studies\(^{18-21}\) were used for materials that were not analyzed, such as NSL-F, SL-F, M(Co), M(W), M(Pa), M(F), and M(Pl).

After all the distribution ratios had been calculated, the distribution ratio of each element was arranged by the destination of each material, such as landfill, aggregate, scrap iron, and incineration or fuel. For this, it was necessary to separate SL-D into float and sink fractions. The physical composition of each fraction was estimated by the physical composition of SL-D and the density of each component. Then, after determining the physical composition of the float [SL-DF] and sink [SL-DS]...
Table 1 Mass of collected material and ratio to input or sum of amount collected.

<table>
<thead>
<tr>
<th>Collected item</th>
<th>NSL-A</th>
<th>NSL-B</th>
<th>NSL-F</th>
<th>SL-A</th>
<th>SL-B</th>
<th>SL-C</th>
<th>SL-D</th>
<th>SL-E</th>
<th>SL-F</th>
<th>M</th>
<th>Sum</th>
<th>Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass [kg]</td>
<td>421</td>
<td>174</td>
<td>13</td>
<td>144</td>
<td>62</td>
<td>127</td>
<td>250</td>
<td>130</td>
<td>23</td>
<td>163</td>
<td>1506</td>
<td>234</td>
</tr>
<tr>
<td>Ratio to input [%]</td>
<td>24</td>
<td>10</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>1</td>
<td>9</td>
<td>87</td>
<td>13</td>
</tr>
<tr>
<td>Ratio to sum of collected [%]</td>
<td>28</td>
<td>12</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>8</td>
<td>17</td>
<td>9</td>
<td>2</td>
<td>11</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

fractions, the IL and metal contents of each were calculated using data obtained in previous studies18-21).

3. RESULTS AND DISCUSSION

(1) Mass distribution of batch experiment

Table 1 shows the quantity collected at each point, the proportion of the input, and the proportion of the sum collected. The total weight of the collected material was 1506 kg, indicating a recovery ratio of 87%. The losses were attributable to escape as dust, small particles that fell off the conveyor belt, and evaporation during the process. This conclusion was reached together with the facility personnel although the precise reasons for the loss could not be determined. From this point onward, ratios were calculated related to the sum of collected mass, assuming that the loss occurred uniformly for each type of material.

The highest mass distribution was that of NSL-A with a ratio of 28%. The mass distributed to SL-A was also high (10%). These observations indicated that the quantity of fine material less than 8 mm was large and accounted for about 40% of the total even though it must be disposed of in the landfill. This was followed by SL-D, which had a mass distribution of 17%. It was surprising that 11% was recovered as recyclable material manually by the 5 workers in the 15 min required for the batch experiment. The efficiency of hand-sorting was much higher than expected.

(2) Characteristics of separated materials

Figure 2 shows the physical compositions of the 7 materials obtained. NSL-A and SL-A contained fine materials of less 2 mm in size, and almost 80% was difficult to classify by eye. The rest was mainly concrete (15%). NSL-B and SL-B, which are used as aggregate, were mainly concrete (70%-80%). SL-E, which is mainly utilized as fuel, was comprised of paper and plastic (80%). Hence, materials separated for further use have compositions suitable for their destination. On the other hand, SL-C and SL-D contained various components still in a mixed state.

The IL, TOC, and water content results are shown in Fig. 3. The IL of NSL-A and SL-A was 11.5% and 12.4%, respectively, and both exceeded the acceptance criteria of 5% necessary for disposal in the least-controlled landfill. The TOC of NSL-A and SL-A were 6% and 5%, respectively. As the percentages of organic components, such as wood, paper, and plastics, accounted for 3% of the physical composition, the fine fraction less than 2 mm appeared to contain some types of organic substance and influenced the TOC results. Although the nature of the organic matter in the fine particles could not be confirmed in this study, Inoue reported that MCDW treatment residue contained starch from gypsum drywall20). Hence, it is possible that the same types of organic matter were present in the samples used in the present study. The IL of NSL-B was low (3%) but SL-B separated after shredding had a slightly higher IL. SL-D and SL-E had high IL because they contained many organic components. The water content was highest in NSL-A and SL-A. Both SL-C and SL-D, which had a relatively mixed state, contained nearly 10% water, but the heavy fractions (NSL-B and SL-B) and large fraction (SL-E) contained less water.

The metal content of each material is shown in Fig. 4 sorted in descending order. The ranges of each metal content were within about one digit. Ca was the most abundant element found. The Ca content of the fine fraction (NSL-A and SL-A) was almost 15% and was 18%-19% of the heavy fraction. This observation agrees closely with the findings of Brunner and Stampflii16), who reported that inorganic fractions, i.e., less than 80 mm and heavy fractions, separated by the sorting process contained 18% and 16% calcium, respectively. Figure 4 also shows that the order of metal content from high to low is similar among the materials, and that SL-E has the lowest percentage.
content for all metals. From the comparison with the Clarke number, which is plotted to show the differences with the metal content of the earth’s crust, the obtained materials contained less Al, Na, and K, but some materials showed higher Pb and Zn contents. This tendency was the same as that identified by Brunner and Stampfli. SL-C had the highest Pb content among the materials with a value of 107 mg/kg and NSL-B also had a high level (97 mg/kg). The Pb contents of NSL-A and SL-A, the distribution ratios of which were high, were not particularly low (58 mg/kg and 46 mg/kg, respectively). Aqua regia digestion was used for metal analysis in this study, so direct comparison with the criteria of the Japanese Soil Contamination Countermeasures Law may be inappropriate because it requires hydrochloric acid extraction. However, given that aqua regia digestion represents stronger extraction conditions than that with hydrochloric acid, none of the separated fractions is likely to exceed the Pb criteria of 150 mg/kg. However, Ono confirmed that the results of leaching tests conducted for some fractions obtained by a similar sorting process did exceed the landfill criteria for Pb. Therefore, further evaluation regarding leaching characteristics is required.

(3) Distribution ratio of element in sorting process

Figure 5 shows the distribution ratio of each element determined from the mass distribution and the analytical data of each material separated. The figure is organized by arranging each material according to its destination. Materials separated for disposal, which included NSL-A, SL-A, SL-C, and SL-DS, accounted for 58% of the total mass, and many elements were distributed in this group, including more than 60% of Al, Ca, Cr, Cu, and Mg.
NSL-A contributed the most to this group. For the materials used as aggregate (NSL-B, SL-B, and M(Co)), most elements were transferred to them at a level of 20% and the organic matter (IL) was less. For materials separated by the magnetic separator (NSL-F and SL-F) and ferrous metal separated by manual sorting (M(F)), the distribution of Fe was quite high, and 71% of Fe was concentrated in this group. Note that Fe recovered by manual sorting was comparable to that recovered by the magnetic separator. Organic matter (IL) was mainly distributed to SL-D and SL-E, which contained large amounts of paper, plastic, and wood. Its distributions to SL-DF and SL-E were 23% and 35%, respectively. Due to the high water contents of NSL-A and SL-A, 72% of water was distributed to the fraction sent to landfill.

Based on Fig. 5, the flow of mass, organic matter, Fe, and Pb in the process is shown in Fig. 6. Although 57% of the mass was separated for disposal, 43% of the mass was diverted from disposal and directed to recycling. About 69% of the organic matter was separated for incineration or use as alternative fuel, and 71% of Fe was recovered from mixed waste for recycling. These results indicated that the sorting process can be regarded as functioning effectively for material separation of MCDW. However, for heavy metals such as Pb, the distribution ratio to fractions sent to landfill was still relatively high. Hence, from viewpoint of both resource conservation and prevention of risk caused by landfills, diversion of metal from the landfill fraction requires further improvement. However, because the fine fractions (NSL-A and SL-A) contribute the most to these metal distributions, this will require some investigation into the feasibility and benefits of further processing.

This study was performed to assess how the sorting process can improve the quality of waste that is disposed of. To assess the improvement of the quality of landfilled waste, the contents of organic matter, Fe, Cu, Zn, and Pb in the original mixed waste were compared with the fraction separated for final disposal by the sorting process. The contents of each element in the original mixed waste were calculated by dividing the sum of the quantities of each element diverted to each fraction by the sum of the mass of each fraction. On the other hand, their contents in the fraction separated for disposal were calculated by dividing the quantity of each element distributed to each fraction by the mass of each fraction.

Figure 7 shows the differences in each content between the original mixed waste and the separated fraction. The IL decreased to half as a result of diverting 69% of the organic matter to the large fraction for incineration. The Fe content also decreased to one third. However, there were no significant differences for Pb, Cu, or Zn. This was because half of the input mass is sent to landfill anyway even if more than half of the Cu, Zn, and Pb are distributed to the materials disposed of into the landfill as indicated in Fig. 5.

Therefore, it seems that treating MCDW waste in a sorting process is effective for decreasing the organic and Fe loads. In addition, even if the mass that was to be disposed of was reduced, the content of heavy metals didn't increase but remained the same.

4. SUMMARY

A batch experiment was performed at a real operational facility to investigate the material separation performance of an MCDW sorting process. From the measurement of each output mass and analysis of ignition loss and metal content,
distribution ratios of them were calculated and yielded the following results.

The fine material under 8 mm destined for final disposal accounted for almost 40% of the total mass. It was not suitable for disposal in the least-controlled type of landfill because its IL exceeded the acceptance criteria.

The separation of organic matter and ferrous metal was excellent; nearly 70% was diverted from final disposal and separated out for recycling.

The distribution ratios of heavy metals, such as Pb and Zn, in the materials destined for final disposal were relatively high. Therefore, the diversion of metal from the landfilled fraction must be improved further.

Although the distribution ratios of metals in material destined for landfill were high, their contents were not significantly changed. Moreover, the organic matter contents in materials destined for landfill were reduced by half.

Therefore, the major functions of the sorting process were reduction of mass, reduction of the organic load in landfill material, and diversion of Fe from MCDW to recycling.

ACKNOWLEDGMENT: The investigation conducted in this study was achieved with the collaboration of Kanto Kensetsu Haikibutsu Kyodo Kumiai. We are grateful for their cooperation.

REFERENCES
2) European Commission, Management of Construction and Demolition Waste Working Document No1, DG ENV.E.3, 4 April 2000
22) Inoue Y.: Mechanisms of strong hydrogen sulfide gas formation in inert industrial waste landfill sites and countermeasures, Research Report from the National Institute for Environmental Studies, Japan, No.188. 2005.

(Received May 23, 2008)