Reduction and utilization of fine residue generated from mixed construction and demolition waste sorting facilities

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Introduction

Sustainable development can be defined as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition was used for the first time in 1987 by the World Commission on Environment and Development of the UN, created in 1983. Its report entitled “Our common future” refers about the global problem of the rapid deterioration of the physical environment and the negative impact it generates to the economic and social development. To deal with this, among many other suggestions, the commission request to the world governments to ensure that the policies and budgets of all their agencies and institutions promote sustainable development. This is one reason why since recent years it is becoming more crucial for various governments and non-governmental institutions around the world to monitor the generation of waste and the recycling rate, in order to minimize the former and increase the latter.

Construction and demolition waste (CDW) is one of the major solid wastes generated from industrial sectors in every country. In Japan, nearly 20% of the industrial waste was generated from the construction sector in 2007. However, by enforcement of the Construction Material Recycling Law, several kinds of CDW such as concrete and asphalt have been recycled or reused at very high rates. On the contrary, as for mixed construction and demolition waste (MCDW), almost one third was disposed of into landfills.

Fig. 1 shows the recycling and disposal of each CDW category in Japan. Concrete and asphalt-concrete represented an 81% of total generation. Also, their recycling rates were extraordinarily high, over 97%. On the other hand, mixed CDW (MCDW) had very low recycling rates of about 32%. It can be defined as CDW containing both recyclable and non-recyclable materials, which have not been separated at source. It is extremely difficult to recycle because it comprises materials with different characteristics (i.e., size, density) such as concrete, wood, asphalt, gypsum (from drywall), metals, bricks, glass, plastics, soil and rocks.

One of Japan's targets for establishing a sound material-cycle society is to reduce the amount of MCDW sent to landfills. Sorting process of MCDW is key for achieving it. Hence, in this study, sorting process of MCDW was investigated in terms of material recovery and how to improve its efficiency was discussed.

Fig. 2 indicates how MCDW was sorted in 2008. While almost 37% (1 Mt) was directly landfilled, the other 63% (1.7 Mt) was sent to a sorting facility in order to recover recyclable materials to reduce the amount for final disposal. By such process, 33% (0.9 Mt) was recovered; nevertheless 22% (0.6 Mt) became residue that was landfilled. In total, 59% of the MCDW generated was disposed of in a landfill. A major issue of the sorting process was the generation of the fine residue which was thought to have the potential of hydrogen sulfide (H\textsubscript{2}S) formation because it contains both gypsum and organic matter. The most evident problem related to H\textsubscript{2}S is its unpleasant odor (like rotten eggs), but also health problems due to a high exposure been reported, an even death at high concentrations. Thus, separation methodology of gypsum and organic matter from fine residue generated from the process was also studied. Moreover, the potential of hydrogen sulfide formation in case of utilization in the environment was assessed by examining leaching behavior of sulfate and organic matter from fine residue.

Research Objectives

In Japan, some years ago, MCDW residue was disposed of in a least-controlled landfill, but a study from Inoue [1] found out that the gypsum contained in it was a source of SO\textsubscript{4}\textsuperscript{2-} and organic matter, responsible for the generation of H\textsubscript{2}S after being landfilled, mainly because of the action of SRB (sulfate-reducing bacteria) and more organic matter contained into the landfill. Because of this finding, a regulation in 2005 established an acceptance criterion of 5% ignition loss (IL) for this category of landfill. Since that moment, residue has...
been disposed of into a controlled landfill, which represents a high cost for the CDW industry.

The main objective of the research is to find effective ways to deal with the MCDW residue generated at sorting facilities, either by:
- Reducing the amount of residue generated, or by;
- Improving the quality of residue (by removing undesirable substances from it like gypsum and organic matter), to make it suitable for disposal into a least-controlled landfill, or by;
- Figuring out alternative ways of disposal/reuse that do not pose an environmental risk or a high economical cost.

The samples used for the analytical experiments were obtained in a single facility. This was done in order to properly evaluate how changes in the flow process affected the residue (amount generated and content of undesirable materials). Even though it is advantageous in that way, it is also difficult to generalize the findings of the research. Therefore, every facility would have to adjust the results shown here to their own characteristics: layout of the facility, kind of MCDW accepted, etc.

### Diagnosis of a mixed construction and demolition waste sorting facility

In order to deal with the problem of residue, the first step is to understand how it generates, how its components are distributed during the sorting process at facilities, how much amount it is generated and what materials it contains. This information will be used to reduce the amount of residue and to improve its quality, by increasing the recycling ratio and removing undesirable materials. To achieve this, in August of 2007 a sorting facility located in Kanto area, in eastern Japan, was diagnosed. Several in-situ tests were performed, including a batch test, where MCDW was input into the sorting process, as shown in Fig. 3.

The first goal was to determine in which outputs were accumulated the highest amounts of undesirable materials (namely gypsum and organic matter). The second one was to evaluate the efficiency of the sorting process in terms of diverting organic matter, gypsum and metals away from the residue, and in the recovery of recyclable materials.

Fig. 4 shows the analytical results for the outputs. The one with the highest amount of pollutants was <8A. The first problem was its high amount generated, representing almost a 28% of the mass distribution. It had the highest gypsum content, with 168 g/kg, which represented a 52.4% of all the gypsum distribution. It had a high IL of 11.5%, way over the maximum permitted level of 5%. It also accounted for the highest distributions of heavy metals, as 39% of Cr and 29% of Pb. Therefore, Line A is the part of the sorting process that the facility must modify at first, in order to improve this problematic.

With respect to the efficiency of the process Fig. 5 shows the flow of materials. Over 57% of the output mass is being landfilled. Then, the amount of residue generated is a significant issue. Besides, almost 80% of the gypsum was diverted to landfills, as well as 55% of Pb and almost 70% of Cr. The separation of organic matter was excellent; nearly 70% was sent to incinerators, still, a considerable amount of it was found in residue; in fact, because of the high IL of residue, it has to be disposed of in a controlled landfill. Therefore, the quality of residue is also a problem presented in this facility. The recycling of ferrous metal was excellent, with a 70% of recycling rate.

These results were communicated to the facility management, especially the problems concerned with line A, and based on them the flow process was modified, in order to improve the sorting efficiency and deal in a better way with the problem of residue.
Improvement of sorting efficiency by process modification

It is extremely beneficial to improve the separation efficiency of MCDW sorting facilities, because that would increase the recycling rate and reduce the disposal rate (into landfills or incinerators). This would diminish the operative cost of the facility and the impact to the environment. To achieve this, the results obtained in the previous section were communicated to the facility management. They decided to modify the flow process (as shown in Fig. 6), especially Line A. As the undesirable materials (especially gypsum) seemed to be concentrated in the small size particles, the size of the first screen was reduced from 30 cm to 12 cm, and the second one in that line was reduced from 8 cm to 6 cm. This way, the amount of residue to be landfilled was expected to be reduced. Several air separators were placed to separate light materials from the heavy ones, improving with this the quality of the latter. To evaluate the effectiveness of those changes, the MCDW sorting facility was visited again in the summer of 2009.

In this section, the sorting facility previously described was re-diagnosed in order to assess how the modifications on the flow process affected the amount of residue to be landfilled and also the impact it had on its quality. Also, in order to avoid a problem of representativeness, three batch tests were performed on different days, with a total of approximately 15 tons of MCDW used as input.

Fig. 7 shows the modified flow of materials. The rate of disposal at landfill decreased from 57% to 23% due to the current flow process. This notoriously decreased the amount of material to be landfilled. The recycling rate increased from 27% up to a 50% (44% was crushed stone used as aggregate for road-base production, and 6% was iron recovered from magnetic and manual separation). This accomplishment contributed to reduce the amount of material to be disposed of. The separation of organic carbon improved from a 69% up to an 82%, which was diverted to incineration/fuel. This indicates that a 27% of the output mass contained the 82% of the TOC and an 83% of the heating value, which are very good indicators. This was helped in part by the fact that most of the organic matter seemed to be contained in the large size outputs (containing lots of paper, plastics and wood, among others). This contributed to improve the quality of the residue, because less organic matter was diverted to it. The recovery rate of iron increased from 71% up to an 82%. This accomplishment also contributed to improve the quality of residue.

In order to contribute with the goal of reducing the amount of material to be landfilled, it was proposed to mix up output C with output I in a ratio of 1:1, because output C had very low IL and TOC, as shown in Fig. 8. The combined material will have a TOC of about 4% with an IL of about 11%, and could be used as aggregate. This way, the amount of material to be landfilled would eventually drop from 23% to 2%, increasing the recycling ratio up to a 70%. Nevertheless, this proposal was recommended to the facility management but has not been implemented (more in depth studies are required to avoid an environmental impact).

At the end, still a lot of progress must be done. Almost one fourth of the output mass must be disposed of in a controlled landfill, due to an 8% of TOC and an 18% of IL (very much over the 5% limit), as well as other undesirable substances like 45% of the recovered sulfur, and high contents of metals. That is, the amount of residue must be reduced and its quality improved.

In order to continue working on the research objectives, the next section analyzes the outputs disposed of in landfills, to determine which density range concentrates the most of the undesirable substances (gypsum and organic matter). This information would allow its removal, which would improve the quality of residue.
Heavy liquid separation of fine residue

As indicated in the results obtained during the first diagnostic to the sorting facility, the content of gypsum in small size outputs (<8A, <8B, Heavy-A, Heavy-B, Light) was exceedingly high, especially residue <8A with a 16.9% content.

Still several outputs are disposed of in controlled landfills, where there are relatively high amounts of organic matter. If favorable conditions for SRB are fulfilled, H2S would be easily generated because residue can become a source of SO4^-2 (from gypsum). Then, if sulfate (or gypsum) can be removed from these residues, the potential of H2S generation can be reduced. Moreover, even in circumstances where no organic matter is provided, perhaps H2S may generate from the organic matter contained in the residue. In such case, it is also recommendable to reduce the amount of organic matter in the residue. Therefore, it is required to find ways to remove this gypsum out of the residue, as an option to improve its quality.

It is considered that gypsum contained in the residue is derived from the drywall accepted into the sorting process. Drywall has a relatively low density because of its high porosity. In contrast, pure gypsum crystals have a density of 2.4 g/cm^3. Therefore, it can be determined whether gypsum appears as drywall or fine particles by identifying the density range in which the gypsum is concentrated. If this can be achieved, it may also be possible to separate gypsum from other materials.

The sorting facility has already used screens for size separation, magnetic separation, gravity separation, etc., but still the gypsum has not been properly removed. Fig. 9 shows the results obtained by Asakura et al., [2]. In their research, particles from the sample were removed by size, and then IL, DOC, gypsum and wood content were measured to the remaining material. Fig. a) shows the results obtained by removing at first the smallest particles (0.075 mm screen) and gradually increasing the size of the screen up to 2 mm. The results showed that the IL remained stable, while the DOC and gypsum content decreased. Fig. b) shows the reverse process, where the screen of 2 mm was used at first and gradually the size of the screen was decreased to 0.25 mm. In this case, the IL increased, as larger pieces of wood were removed, but also the DOC and gypsum content steadily increased. These results indicate that in the residue, both the organic matter and the gypsum were concentrated in the very small size particles, therefore, could not be properly separated based on their sizes. Therefore, in this study, a density separation approach would be more effective to achieve the separation of both materials. For this, five output samples (<8A, Heavy A, <8B, Heavy B and Light), were subjected to a heavy liquid separation, in order to identify which density range contained the highest amounts of them.

The results showed (Fig. 10) that 93% of the gypsum of output <8A was concentrated in a density range of 1.59–2.28 g/cm^3, in which 24% of the output mass was concentrated. These findings indicate that since gypsum is mainly distributed in the fine fraction and has a high density, the amount of gypsum going to landfills can be reduced by first separating the fine fraction from MCDW and then removing particles in the density range of 1.59–2.28 g/cm^3. These measures could remove 24% of the mass, containing 93% of the gypsum, resulting in a gypsum concentration of only 1.55% in the final residue. This would consequently reduce the potential of H2S generation in landfills, providing economic benefits for the CDW related industry and enhancing the safety of landfill workers.

This study conducted heavy liquid separation, which necessarily required the use of a wet process and hazardous chemicals. In practical applications, however, a dry separation process that can provide separation at this high-density range would be preferable.

This separation method was proposed to the sorting facility management as an option to improve the quality of residue but it is not implemented at present. Therefore, in order to keep looking for options to deal with the residue, the potential of H2S generation if used in contact with a low organic matter environment was analyzed in the next chapter.
H₂S generation potential from MCDW fine residue

In the previous sections, several options have been analyzed to improve the quality of residue and also to reduce the amount of residue generated from the sorting facilities, which are two of the objectives of this research. In this section it will be analyzed the third option proposed: to figure out alternative ways of disposal/reuse that pose neither an environmental risk nor a high economical cost.

As mentioned before, Inoue reported that H₂S generation in landfills significantly increased by disposal of waste drywall because it contained sulfate and organic matter. As it is thought that MCDW residue is a source of organic matter and sulfate (from gypsum), the regulation implemented because of his research banned the residue from being disposed of in least-controlled landfills. Instead, it should be disposed of in controlled landfills, which increased the disposal cost for the MCDW industry. However, except for the residue with quite IL, H₂S generation was hardly identified in Inoue's study. It was measured the IL and DOC of residue and drywall samples. In the case of the residues used during the present research, the IL has been around 10%. For residues with IL around 10%, Inoue found very low levels of COD (less than 70 mg/L). Also, the initial BOD was evaluated to measure the generation of H₂S. It was found that for DOMs around 100 mg/L (like the samples of this research), the amount of H₂S generated was remarkably low in some cases (less than 1 ppm) and was not found at all in many other cases. Therefore, disposal of the residue into controlled landfills rather results in the rise of H₂S. Based on this, it is considered that potential of H₂S generation from MCDW residue must be evaluated appropriately from the viewpoint of releasing of sulfate and organic matter.

There are several fertilizers, soil conditioners and material for construction that contain sulfate and some of them also contain organic matter. These materials are regularly used for agricultural and civil engineering purposes without experiencing any environmental issue. In United States and other countries there are companies that recycle drywall, separate the paper and the gypsum and then sell the gypsum for a large number of agricultural and civil engineering purposes. The Department of Resources Recycling and Recovery of California, USA, (CalRecycle) recommends the use of drywall waste as a soil amendment and also mentions the benefits of the use of gypsum in soils. The Construction Materials Recycling Association, also in the US, recommends using recycled drywall to improve the characteristics of the soil for construction or agricultural purposes, mainly based on the researches of Dr. Timothy Townsend. All this because it is well documented the benefits of gypsum use in soils. Wallace [3] described thirty three benefits of gypsum as agricultural fertilizer. Even more, Jang and Townsend [4] proposed to use CDW debris fines as fill for construction purposes.

Therefore, the purpose of this section is to examine the potential of H₂S generation from residue (which contains gypsum). For this, the leaching behavior of different kinds of materials, containing both sulfate and organic matter, will be analyzed to compare them against the residue's. Eleven samples were used, including MCDW residue, fertilizers, soil conditioners and materials for construction. The obtained leachate was analyzed for sulfate content, TOC, VFA (acetic, lactic and propionic acid) and glucose, in order to determine how it was different among the samples.

The generation of H₂S is as follows: In the solid state, samples are composed of both organic and inorganic fractions. The organic fraction comprises easy-to-degrade materials (carbohydrates, fats and proteins) and hard-to-degrade materials (cellulose, hemi-cellulose and lignin). The inorganic fraction provides the sulfate. Then, by leaching the hydrolysis process occurs, and the material are transferred to the liquid phase as sugars, amino-acids, fatty acids and other dissolved organic matter (DOM). The sulfate is also transferred to the liquid phase from the inorganic fraction. At this point, the organic fraction starts the acidogenesis process, where lactic acid, acetic acid, propionic acid, butyrate and formate are originated. Finally, the organic acids serve as substrate and electron donor for the SRB (sulfate-reducing bacteria), and the SO₄ serves as an electron acceptor and it is, therefore, reduced. The chemical reactions that occur during this process are indicated by several researchers. Ollivier and Magot [5] indicated that lactate is a classical substrate for almost all species of SRB. Barton [6] shows that lactate and sulfate can react to generate H₂S by the following equation:

\[
\text{Lactate} + 1.5\text{SO}_4^{2-} + 4\text{H} \rightarrow 3\text{CO}_2 + 1.5\text{H}_2\text{S} + 3\text{H}_2\text{O}
\]

Lamleam and Annachhatre [7] also showed another equation for the same transformation:

\[
\text{Lactate} + 1.5\text{H}_2\text{SO}_4 \rightarrow \text{CH}_3\text{COOH} + \text{CO}_2 + 0.5\text{H}_2\text{S} + \text{H}_2\text{O}
\]

They also show the equation for the SRB’s utilization of Acetate:

\[
\text{Acetate} + \text{SO}_4^{2-} \rightarrow \text{HS}^- + 2\text{HCO}_3^- 
\]

Barton also indicates that some SRBs can grow by fermentation of propionate, as shown in the following two equations given by Lamleam and Annachhatre:

\[
\text{Propionate} + \text{SO}_4^{2-} + \text{H}_2 \rightarrow \text{HS}^- + \text{HCO}_3^- + \text{acetate} + \text{H}_2\text{O} 
\]

\[
\text{Propionate} + 2\text{SO}_4^{2-} + \text{H}_2 \rightarrow 2\text{HS}^- + 3\text{HCO}_3^- + \text{H}_2\text{O} 
\]

Also, a model was used to estimate the generation of H₂S from each sample if used in the environment. It used the following assumptions (shown in Fig. 11): an annual precipitation of 1,700 mm/y, an evaporation rate of 700 mm/y and consequently an infiltration rate of 1,000 mm/y, all this over a surface of one square meter of sample (the basic cell used for the calculations). For each sample, different masses were used, depending on the scenarios (Scenario 1: 9 kg of gypsum per square meter, Scenario 2: 0.5 kg of gypsum per square meter,

![Figure 11: Assumptions for the daily estimation of H₂S generation](image)
concentrations of the following species were calculated: the organic carbon and sulfate. In the liquid fraction, the pressure of each H2S and CO2 in the gas fraction, based on dissociation constants. The model calculated the leaching process. The final results were expressed in ppm. The model did not besides, it kept leaching out organic matter for a longer period compared with the other materials. The residue indicated that the residues did not generate higher amounts compared to the other materials. The residue amounts compared to the other materials. The residue could be used for filling or civil engineering purposes, at rates of 100 kg per square meter, and the amount of H2S generated would not produce any adverse effects on the human being.

MCDW residue leached out a larger amount of organic carbon compared with the other materials. Besides, it kept leaching out organic matter for a longer period that the rest of the materials. Nevertheless, the fact that the leaching behavior of glucose and VFA is similar among the 4 kinds of materials indicates that not all the organic carbon leached out from residue can be used by SRB to generate H2S. Still, the amount of glucose and VFA leached out by residue is slightly higher than the leached out by the most of the soil conditioners and materials for construction. The leaching behavior of sulfate was highly similar among all the samples analyzed. It seemed to be mainly dominated by the solubility of gypsum.

The results of the H2S generation model (Fig. 12) indicated that the residues did not generate higher amounts compared to the other materials. The residue could be used for filling or civil engineering purposes, at rates of 100 kg per square meter, and the amount of H2S generated would not produce any adverse effects on the human being.

**Figure 12: H2S concentration for different scenarios**

**References**


