# ADR – a New Method for Dry Classification

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## 1. Abstract

In processing MSWI-bottom-ash (IBA) and C&D-waste (CDW) problems in classification and separation occur when handling the zero to twelve millimeter fraction. These problems are caused by fines (0 to 2 mm) and the moisture associated with these fines. In this paper results are presented of an experimental study into the effects of a new type of classification unit, called Advanced Dry Recovery (ADR). In this study the particle size distribution and moisture content of the materials produced by the ADR are analyzed. It was found that more than 70 percent of the fines were removed from the produced material.

To determine the improvement in the separation possibilities after processing the material with the ADR, the recovery of materials of interest is investigated. In zero to eight millimeter IBA the recovery of non-ferrous more than doubled. Furthermore a comparative study on the aluminum content in IBA has been carried out to determine the effects of aging. It was found that aging IBA results in a reduction of almost seven kilogram of aluminum per ton of wet bottom ash

## 2. Introduction

In order to reach a more sustainable society, technologies are being developed to recycle municipal solid waste incinerator bottom ash (IBA) and construction and demolition waste (CDW) into high grade metal and mineral products instead of road foundation materials [1, 3, 9, 13]. To enable such high-grade recycling a strict classification according to particle size is necessary prior to material. However, size classification of the fine fraction (0 to 12 mm) is problematic at the typical moisture contents of IBA and CDW. Drying the material to lower moisture content consumes too much energy and wet methods produce sludge with a high negative value. Experiments with aging and dry- season processing of IBA, showed improved processability, but the recovery of metals is still not satisfactory [2, 6, 12]. The problematic moisture in the fine fraction of IBA and CDW is primarily associated with the zero to two milimeter grains. This fraction contains the most moisture and makes the entire zero to twelve millimetres fraction sticky. Therefore, the removal of the zero to twelve millimetres fraction is essential in making the remainder processable by e.g. magnets, eddy current separators (ECS) and wind sifters. If these conventional techniques become available for the zero to twelve millimetres fraction it is possible to reach a high grade metal and mineral recycling. Incinerator bottom ash has a high non-ferrous (NF) content [7, 15]. It is interesting to recover this NF from an economical as well as an ecological point of view. Especially aluminum is of interest, because of its high price and large carbon footprint. Currently, only the aluminum in the plus twelve millimetres fraction is being recovered successfully [10]. The low recovery of non-ferrous metals from the zero to twelve millimetres fraction has two disadvantages. It reduces the overall recycling grade, resulting in a higher depletion of natural resources and the metals that remain in the IBA may be hazardous in the long term because of their leaching properties [5].

In the coming twenty years there will be a strong increase in the amount of CDW (in Europe) because of the construction peak in the 1950‘s and the shortening lifespan of buildings. In addition, a reduction in the current main outlet, road foundations, is expected. The net growth of infrastructure will diminish, resulting in a decreasing need for new road foundation material. This surplus can be used to advantage by recycling the complete CDW-stream into high grade construction products, like aggregates and cement. So far, it has not been economical to remove the contaminations – e.g. wood and steel – from the zero to twelve millimetres size fraction, since this would require complete drying of the product or using a wet process that forms sludge [14].

From the above it can be concluded that a direct dry classification method is needed. By closely examining the physics in classification, a new dry method called Advanced Dry Recovery (ADR) was developed. This method allows classification of the moist material down to two millimetres without drying or the addition of water. In order to investigate the effectiveness of the ADR, two pilot plants are currently in use. Preliminary results on IBA were so convincing that an industrial installation was manufactured at Sluiskil (NL). In order to the study the effects on CDW, a lab-scale unit was built at the faculty of civil engineering of the TU Delft. In this paper results from both installations are presented.

In addition, a study has been done on the effects of aging bottom ash. Currently IBA is often aged to reduce the moisture content and improve the processability [4, 6]. In the course of aging, heat is developed within the IBA which evaporates the water. It is suspected that this heat is created by the reduction of aluminum into aluminum-hydroxide. For the verification of this theory, a simple comparative study has been done to investigate the aluminum content of fresh and aged IBA.

## 3. ADR-technology

Table 1: Properties of main product streams

| | Weight kg | Moisture % |
|---|---|---|
| IBA-rest | 875 | 13.3 |
| NF | 41 | 6.1 |
| Ferro | 84 | – |
| **Total** | **1,000** | – |

The new ADR-unit uses kinetic energy to break the water bond that is formed by the moisture associated with the fine particles (patent pending). Hereafter the fine material can be separated from the coarse material. When the fine (wet) fraction is released from the coarse material, the latter becomes suitable for conventional upgrading processes.

## 4. State of Art

### 4.1. MSWI bottom ash

It is currently the best available technique to remove all NF and ferrous in IBA above 12 mm using magnets and ECS. For the zero to twelve millimetres fraction it is currently the best available technique to age the material for 6 weeks to induce carbonation and reduce its leaching properties. After acceptable leaching values are reached, the material can be used in road foundations, but it needs to be sealed, stored in a recoverable way and monitored for its entire lifespan [4].

Using a Dutch state-of-the-art bottom ash processing facility as a reference, data is presented for the processing of one ton of wet IBA. Within the reference facility, three streams are produced. The wet amount and moisture content of these three streams are shown in Table 1. The size distribution and aluminum content of the dry IBA-rest and NF concentrate are shown in Table 2.

Table 2: Particle size distribution and aluminium contents/recovery

| Particle size | Size distribution | | Aluminium grande | | Alu. Recov. | | Total recovery |
|---|---|---|---|---|---|---|---|
| | Rest | NF-Conc. | Rest | NF-Cons. | Rest | NF-Cons. | |
| mm | % | | % | | kg | | % |
| > 20 | 7.8 | 44.3 | 0.1 | 27.6 | 0.08 | 4.69 | 98.4 |
| 6 – 20 | 16.3 | 29.5 | 0.5 | 49.7 | 0.57 | 5.62 | 90.8 |
| 2 – 6 | 30.0 | 11.8 | 1.3 | 39.8 | 3.06 | 1.8 | 37.1 |
| 2 | 45.9 | 14.4 | 0.7 | 0.6 | 2.61 | 0.03 | 1.27 |
| **Total** | **100** | **100** | **0.8** | **31.6** | **6.32** | **12.14** | **65.8** |

The data show a good aluminum recovery in the plus six millimetres fraction. However, the recovery for the two to six millimetres is significantly lower. One ton of wet IBA contains about 18.5 kg of aluminum, almost 3.1 kg remains in the wo to six millimetres fraction of the IBA-rest and will not be recovered. Separation of this aluminum using an ECS is theoretically possible; however properties of the fine material cause it to be uneconomical. The new ADR technology will enable us to reduce the amount of zero to two millimetres and significantly increase the recoverability of aluminum and other NF in the wo to six millimetres fraction.

## 4.2. Construction and demolition waste

The current primary use of construction and demolition waste is in road foundations. Only a minor part (five percent) is processed so it can be used as aggregates in concrete production. For CDW to be used as aggregate it is necessary to remove all contaminations (e.g. wood and steel).

The current best available technique to process CDW into aggregates is washing or complete drying combined with wind-sifting. Both methods are expensive and energy consuming [8].

In an earlier study into the high grade recycling possibilities of CDW it was tried to separate the different products in CDW using a thermal treatment. Hereafter the material was classified via e.g. sieving and wind sifting. Because the thermal treatment was carried out on almost the entire CDW stream it was found to be uneconomical [9].

The new ADR technology will enable to cost- effectively produce a product that can be easily cleaned from its wood and steel content. Hereafter the product can be reused as aggregate in concrete. In this way the aggregate in CDW is being reused in its original application. The fine fraction (0 to 1 mm) that is separated from the CDW has a high potential to be used in the cement industry.

# 5. Method

The primary goal of the ADR is to reduce the amount of fines within the waste materials. The effects of the ADR on the particle size distribution and moisture content have been investigated for both IBA and CDW. The IBA was processed in the industrial machine in Sluiskil; the CDW was processed using the lab-scale unit at the TU-Delft. For both materials the moisture content and particle size distribution of the input material was determined and compared to the produced fractions.

## 5.1. MSWI bottom ash

The influence of the ADR on IBA was investigated by processing 200 ton of zero to eight millimetres Belgian MSWI-bottom-ash in the industrial plant. The zero to eight millimetres IBA was classified using the ARD into zero to two millimetres fraction and two coarser fractions. Samples were taken of the three output streams to determine the particle size distribution and moisture content.

The produced coarse fractions were led over an ECS to produce two NF-concentrates and a reject fraction. In order to investigate the increase in non-ferrous recovery, the zero to eight millimetres IBA input and the two NF-concentrates were analyzed on their NF-content.

## 5.2. Construction and demolition waste

About 1500 kg of concrete granulate, heavily polluted with wood and ferrous, was acquired from a Dutch breaker. Of this batch a sample was taken of 250 kg of zero to twelve millimetres material. This material was fed, untreated, into the lab-scale ADR-unit at a rate that would correspond to about 120 ton/h for a full-scale machine.

During the process the CDW is split into various products. The cut-point determines the quality of the classification. In order to determine the optimum cut-point, a series of test runs was carried out. Of every run, samples were taken to investigate the size distribution and moisture content. Once the optimum cut-point is determined, the size distribution of the coarse product was polished using a laboratory air knife.

In order to demonstrate the ability to remove the wood contamination, an air-knife operation on the produced material was simulated. The analysis was enhanced by artificial increasing the wood content to 1.3 wt % with wood particles comparable to the original wood contamination.

Figure 1 shows the size distribution of both IBA and CDW. The amount of fines (0 to 1 mm),moisture content and the contamination level – all relative to the dry input – is presented in Table 3.

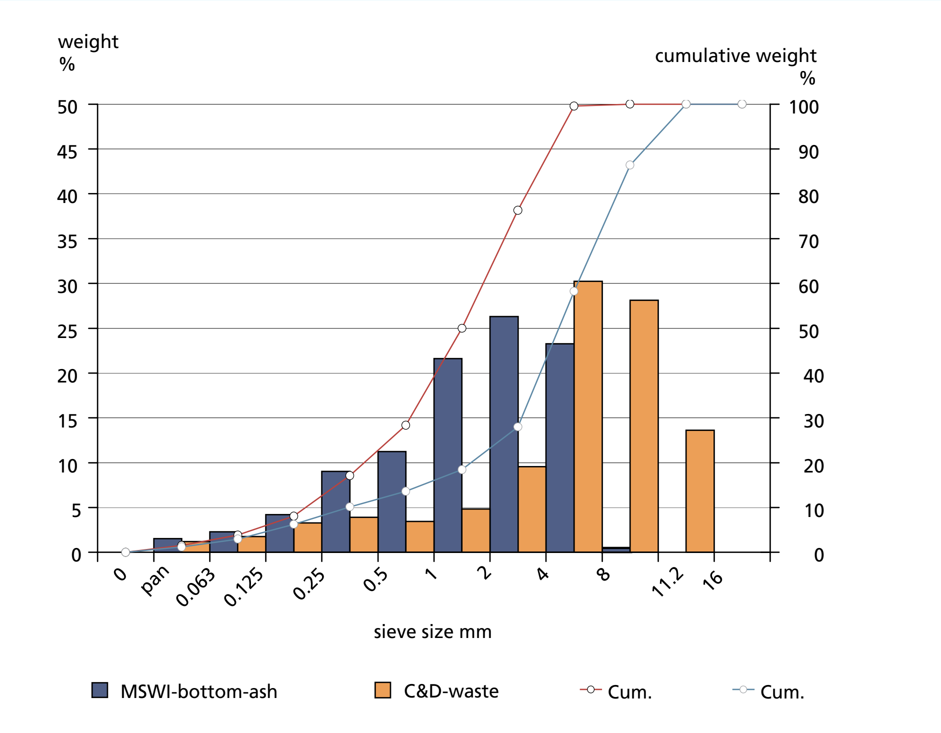


Figure 1: Size distribution of MSWI-bottom-ash and construction and demolition waste

Tabelle 3: Main properties of MSWI-bottom-ash and construction and demolition

| | MSWI-bottom-ash | C&D-waste |
|---|---|---|
| | % | |
| 0 – 1 mm | 28.4 | 13.6 |
| Moisture | 20.5 | 13.3 |
| Non ferrous | 1.15 | – |
| Wood | – | 1.3 |

Table 3 shows that both input materials have a high amount of fines. Moisture is associated with these fines which results in high moisture contents. For both streams the contamination of interest is about 1 %. It must be noted that the IBA has already aged, reducing the amount of recoverable NF, see the following section.

## 5.3. Aging test

To investigate the influence of aging on the aluminum content of bottom ash, a simple comparative study was done on fresh and aged IBA. The material was collected at an MSWI-bottom-ash processing plant, in the Netherlands. Both samples were unprocessed and the aged IBA had aged for ten weeks. Prior to the analysis, the moisture content was determined by drying the material for 24h in an oven at 110 °C. The dry bottom-ash was sieved at two, eight and 16 mm and the amount of aluminum was determined for the 2 to 8 mm and 8 to 16 mm fractions. The zero to two millimetres and + 16 mm fractions were discarded.

In order to determine the aluminum content the following procedure was followed. First, the ferrous material was removed using a magnet. Hereafter the material was pre-concentrated using a metal detector. The 8 to 16 mm concentrate was hand sorted, and the ambiguous particles were crushed in a roll crusher (to 2 mm), sieved and hand sorted again. The two to eight millimetres concentrate was led over an eddy current separator. The reject was crushed (to 1 mm), sieved and hand sorted. This resulted in four aluminum concentrates for both the fresh and aged bottom-ash. The, in total, eight aluminum concentrates were treated with $HNO_3$, prior to weighing, to remove the oxidized aluminum and enhance the further removal of non-alumina.

## 6. Results and discussion

### 6.1. Construction and demolition waste

The CDW was processed using the lab-scale ADR unit. With the results from the test runs, the optimum cut-point was determined. Using this cut-point the input is separated into a fine product (target: 0 to 1 mm) and a coarse product (target: 1 to 12 mm).

The two products were polished using an air knife. Taking the polishing step into account the size distributions given in Figure 2 were measured. The fine and coarse-products were respectively 13.5 and 86.5 wt % of the input material.

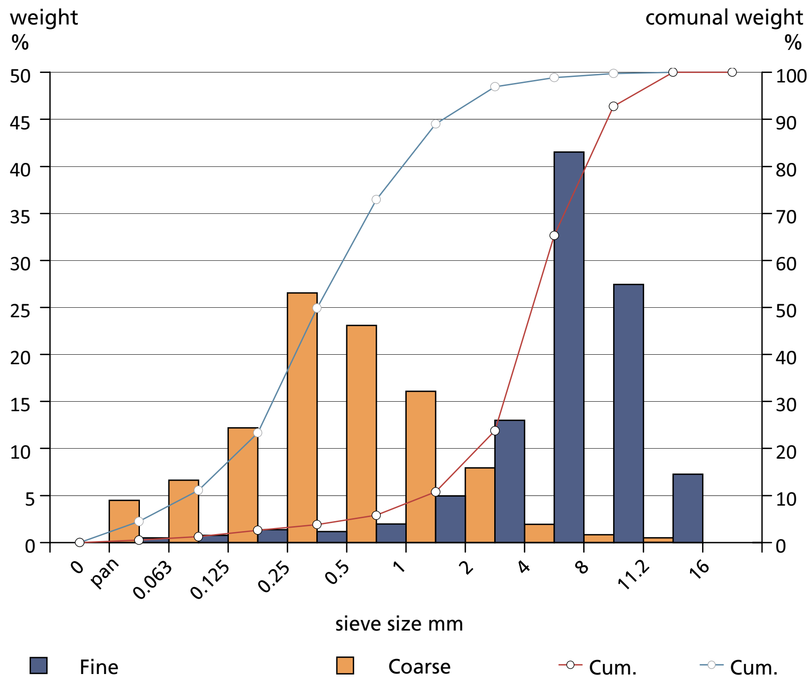


Figure 2: Particle size distribution of construction and demotion waste processed with the ADR technology

The results show the effect of the ADR on the fine material. More than 70 percent of the fines are concentrated into the fine-product, resulting in a coarse-product with a grade of almost 95 percent. Such a strong reduction in fines results in a product that can be further processed using conventional methods.

The moisture content was suspected to be related to the particle size distribution. This was confirmed by a strong linear relation between the fineness* and the moisture content (Figure 3). The parameters of the input material deviate from this line because of breaking and drying effects within the ADR. These results confirm that the moisture is associated with the fine fraction. By removing this fraction, the originally sticky material becomes loose and processable. Table 4 shows the proportions of the produced material, moisture content and grade & recovery of the desired fraction. The coarse-product was further processed using an air-knife. A mineral fraction of one to three millimetres was removed from the product. Because of the geometry and specific weight of wood, all wood particles up to twelve millimetres are concentrated into this one to three millimetres mineral stream. It was found that the recovery of wood in the one to three millimetres product was almost 80 percent. (Table 5).

Table 4: Main properties of construction and demotion waste processed with the ADR technology

| | Fine 0 – 1 mm | Coarse 1 – 12 mm |
|---|---|---|
| | % | |
| kg/kg | 13.5 | 86.5 |
| Moisture | 24.2 | 10.3 |
| Recovery | 72. 9 | 94.2 |
| Grade | 72.0 | 94.3 |

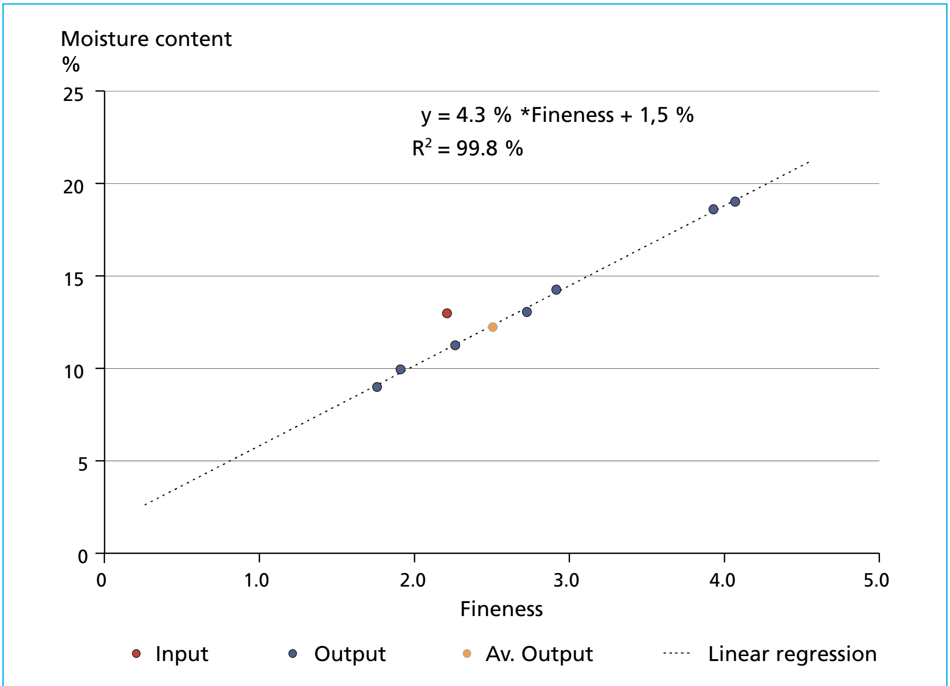


Figure 3: Relation between moisture and fineness

* Expressed as the summation of the cumulative distribution

Table 5: Wood center after air-knife

| | Wood | Wood | Total weight |
|---|---|---|---|
| | % | g | |
| Input | 1.3 | 85.9 | 6,491 |
| 1 – 3 mm | 8.4 | 68.2 | 816 |
| + 3 mm | 0.3 | 17.1 | 5,675 |

The one to three millimetres fraction – which contains the wood contamination – can be processed with e.g. a screw classifier to separate the wood from the minerals. Hereafter the cleaned product can be reunited with the rest of the mineral stream – i.e. the remainder of the coarse-product. By using this technique only 10 to 15 percent of the product stream needs to be cleaned with a wet process, instead of the whole product fraction. This proposed system for wood removal is very robust; if during operation it appears that some wood still remains in the product, the air-knife can be adjusted to improve the recovery of wood.

In the contaminant analysis of the input it was found that the zero to twelve millimetres fraction of CDW contains 0.6 % ± 0.1 % magnetic steel. This ferrous will be concentrated into the coarse-product, which makes it easy to recover by magnetic separation, resulting in a high recovery (close to 100 %). Scrap steel is currently worth about 200 EUR/ton [14], subsequently 0.5 percent of recovered steel is worth 1 EUR per ton of processed CDW. Because the ADR- unit is operated so cheaply the small scrap stream could almost pay the entire process.

The coarse product of CDW can be used as aggregate in concrete, once wood, steel and fines are separated and removed. This will close the cycle of concrete aggregates, reducing the amount of unused waste material and depletion of natural resources. The fines can be a promising material for the cement industry.

## 6.2. MSWI bottom ash

The MSWI bottom ash has been processed in the industrial installation in Sluiskil (NL). Here the ADR produces three streams: a coarse, middle and fine fraction. Figure 4 shows the particle size distribution of these three products.

It can be seen that the produced streams have very distinct particle sizes. The middle and coarse product have a strong reduction in fines. Since the moisture is associated with these fines, the moisture content of the middle and fine fraction has also decreased. These two effects result in a material that can be well processed using an ECS.

Table 6: Main properties of MSWI-bottom-ash processes with ADR

| | Unit | IBA (0 – 8) | Coarse NF | Fine NF |
|---|---|---|---|---|
| Total | kg | 200,000 | 4,944 | 5,458 |
| NF | kg | 1,917 | 1,404 | 306 |
| Grade | % | 0.69 | 28.39 | 5.60 |
| Recovery | % | 89.2 | 73.2 | 15.9 |
| Moisture | % | 20.5 | 7.1 | 19.1 |

Again the determined moisture content of the input, fine, middle and coarse products shows a clear linear relation with the fineness. The tangent and offset of the regression line are slightly higher because of the higher moisture content of the input material.

The two coarse products were led over an ECS. The produced concentrates were analyzed on their NF content and compared to the input. The results are shown in Table 6.

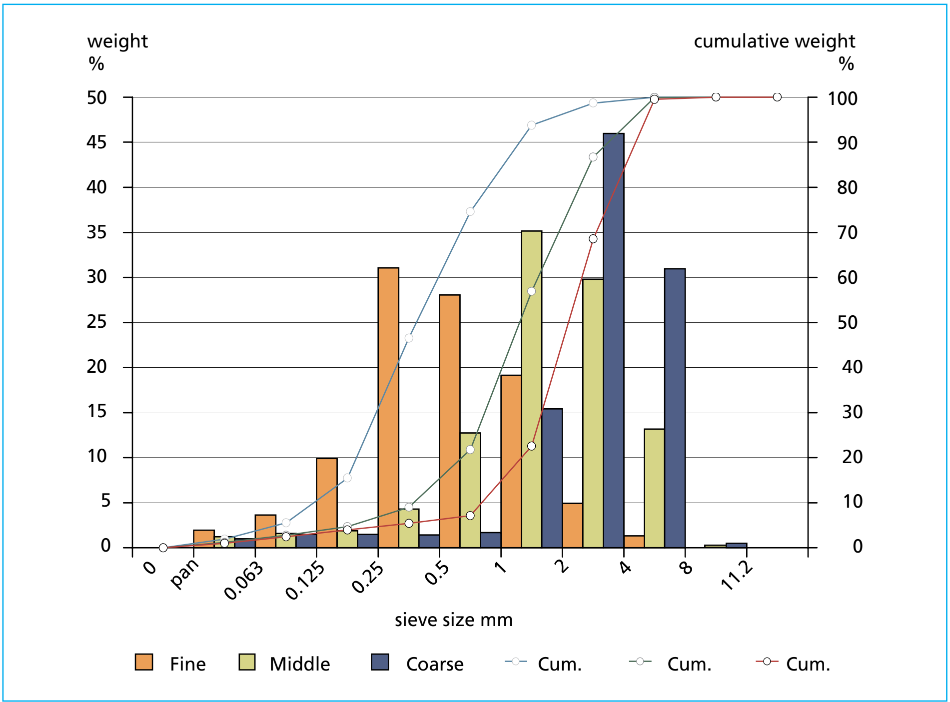


Figure 4: Participle size distribution of MSWI-bottom-ash processed with ADR

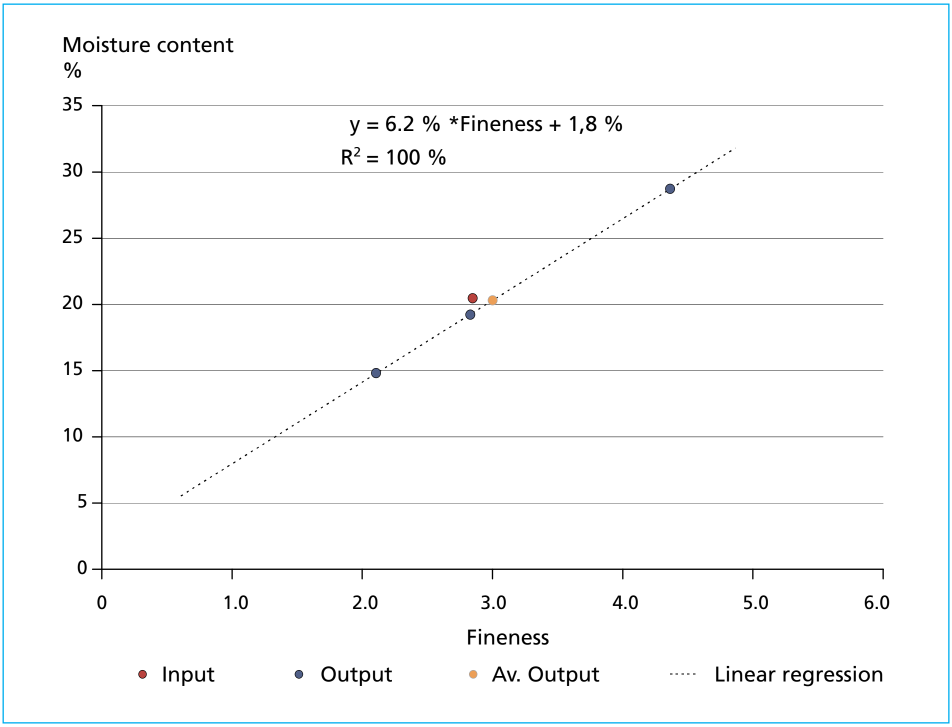


Figure 5: Relation between moisture and fineness

These results show a high recovery of the NF in the zero to eight millimetres fraction – an increase from 37 to 89 percent. It should be noted that the input material used in this experiment (0 to 8 mm IBA) had a lower grade of NF than in the state of the art reference case. This is because of the material used in this test had aged for about six weeks.

The NF found in the mineral rest stream was mostly smaller than two millimetres; this means it would not be recoverable using an ECS. To recover this aluminum it will be necessary to develop a new technology. Fortunately the reject from the ECS has a lot less fines – compared to the zero to eight millimetres input – making it more suitable for road foundation. Furthermore the metal content is reduced significantly and the NF that is still present is very small, so it will oxidize quickly – improving the leaching properties. The fine reject fraction produced in the ADR can be an interesting material in the production of cellular concrete [11].

## 6.3. Aging test

To investigate the influence of aging on the moisture level and aluminum content of IBA, two samples, fresh and aged, were analyzed. The fresh bottom-ash contained about 15 percent moisture versus 13 percent in the aged bottom-ash; this percentage is expressed relative to the wet weight of the bottom ash. This decrease suggests that in a period of ten weeks around 27 kg of water has evaporated out of one ton of wet bottom-ash.

The size distribution and aluminum grade per size fraction are presented in Table 7. It can be seen that in both size fractions the aluminum grade decreases with about 30 percent. The total amount of aluminum in one ton of fresh wet IBA is around 23 kg. If it assumed that the aluminum in the 16 to 40 mm and 0 to two mm fraction will deteriorate to the same extent as in the 2 to 16 mm fraction, the total loss of aluminum in every ton of wet IBA is 6.9 kg.

Table 7: Size distribution and aluminium grade

| | | Size distribution | | Aluminium grade | |
|---|---|---|---|---|---|
| | Unit | Fresh | Aged | Fresh | Aged |
| Total | kg | 22.8 | 19.4 | | |
| > 16 mm | % | 22.6 | 18.6 | | |
| 8-16 mm | % | 23.8 | 21.6 | 3.3 | 2.3 |
| 2-8 mm | % | 24.2 | 29.4 | 2.1 | 1.4 |
| < 2 mm | % | 29.4 | 30.4 | | |

From experience it is known that the temperature of bottom-ash rises from 40 °C to around 80 °C during aging. From the moisture content measurement it is known that about 27 kg of water is evaporated. The energy needed to evaporate the water is about 60 MJ/ton of wet IBA. To elevate the temperature of the wet IBA another 60 MJ of energy is needed. It is suspected that this energy is released in the oxidization of aluminum to aluminum-hydroxide. The energy release in the aluminum oxidation can be calculated according to the redox reaction. From this calculation it follows that around 18 MJ is released for every kilogram of oxidized aluminum. If it is assumed that 6.9 kg of aluminum is lost in every ton of wet bottom-ash, this would result in the 124 MJ of energy, which is around the same that is needed for a temperature elevation of 40 °C and the evaporation of 27 kg of water.

The above makes it reasonable to believe that the heat required for the water evaporation is indeed delivered by the oxidization of aluminum. This oxidization will result in a reduction of the amount of recoverable aluminum. The 6.9 kg of aluminum that has oxidized is worth around 1 EUR/kg [14] resulting in a loss of 7 EUR/ton of wet bottom-ash.

During the determination of the aluminum content in aged and fresh IBA, it appeared that not only the amount of aluminum changes during aging, but also the way in which the remaining aluminum can be found changes. As described in 3.3, the aluminum was partially recovered via direct methods such as hand sorting and eddy current separation. The remaining part was recovered after crushing the material with a roll-crusher. Table 8 shows the grade of aluminum in the uncrushed and crushed 2 to 16 mm fraction.

Table 8: Aluminium grade found in uncrushed and crushed MSWI-bottom-ash

| | Fresh | Aged |
|---|---|---|
| | % | |
| Uncrushed | 2.25 | 1.00 |
| Crushed | 0.45 | 0.80 |

It can be seen that when the IBA has aged, more of the aluminum can only be found after crushing. In practice this can be interpreted as an indication that this aluminum will be harder to recover. If this effect is taken into account, the loss of recoverable aluminum within the 2 to 16 mm will not be around 30 percent but close to 56 percent. Hence, not only the absolute amount of aluminum in bottom-ash decreases during aging, the aluminum that remains will deteriorate to such an extent that the recovery will be lower.

## 7. Conclusions

Problems in the classification and separation of materials of interest from the zero to twelve millimetres fraction in MSWI-bottom-ash (IBA) and Construction & Demolition-waste (CDW) are caused by the fines (0 to 2 mm) and the moisture associated with these fines. A study has been done into the effects of a new type of classification unit, called the Advanced Dry Recovery (ADR). Furthermore a study on the aluminum content in IBA has been done to determine the effects of aging. From these experiments the following conclusions can be drawn.

- The ADR reduces the amount of fines significantly in both IBA and CDW. A reduction of 24 percent and 75 percent was found in the produced IBA-products. A reduction of 53 percent was found in the produced CDW-product.
- The ADR can handle material with the typical moisture content of untreated IBA and CDW; 21 percent and 13 percent respectively.
- The ADR-technology can be used to process IBA and CDW in a similar way. The processing after the ADR will be different.
- The ADR produces a material that can be well processed using conventional methods.

- The recovery of aluminum in the 2 to 8 mm fraction of IBA increases to 89 percent after treatment with the ADR, compared to 37 percent in a state-of-the-art reference case.
- Aged bottom-ash has a significant reduction in aluminum content (30 percent), which can be correlated to the oxidation of the aluminum.
- Because of the way the aluminum is found in fresh and aged IBA, it is expected that the rate of recovery is higher for fresh bottom-ash.

## 6. Further research

The experiments with the ADR have delivered a proof of concept. More research is needed to optimize the functioning and products of the ADR. Furthermore, research is needed to optimize the use of the produced materials.

The metal content in the coarse IBA fraction is very low after the ADR and ECS treatment. The metal that is still present is very small and will probably oxidize quickly. The material is therefore more suitable as road foundation material or even as aggregates in concrete. The new applications of the material need to be studied to guarantee responsible use. This also applies to the produced CDW-aggregate.

The fine zero to two millimetres fraction of both IBA and CDW are now still handled as a waste material. We already managed to reduce the left-over stream from

zero to twelve millimetres fraction to around zero to two millimetres fraction. However the zero to two millimetres fraction material has high potentials and can probably be used in the cement industry, which is especially interesting in light of $CO_2$-reduction.

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