



**LIFE05 ENV/DK/000153**

**Utilisation of ash from incineration of wastewater sludge  
(bio ash) in concrete production**

**Layman's report, 2007**



Spildevandscenter Avedøre

**UNICON** ///



## INTRODUCTION

The objective of the project is to remove technical barriers for the utilisation of wastewater sludge incineration ash (bio ash) in the production of concrete, and at the same time reduce the amount of waste for disposal.



Waste Water Treatment Plant, Avedøre

Incineration of sludge has already for decades been a well-established technology for sludge treatment in Europe. As a result of extension of secondary and tertiary wastewater treatment from implementation of the Urban Waste Water Treatment Directive the generation of bio ash is expected to increase significantly at the European scale. The same effect will be seen from the reduced disposal of sludge in agriculture in some countries. According to the EUROSTAT statistics the total sludge production from urban wastewater treatment plants (WWTPs) can roughly be estimated to 8.9 million tons dry solids (DS) in the 25 EU Member States. The Statistics show rises for sludge incineration during the period 1990 to 2000 in the Netherlands from 12.000 to 180.000 t DS/year and in the UK (England & Wales) from 74.000 to 209.000 t DS/year.

Results from former research projects indicate that bio ash can be added to concrete to substitute fly ash or in some cases even substitute Portland cement, and that the density of bio ash is higher than fly ash but lower than Portland cement. Further, it was indicated that concrete with bio ash has acceptable strength, and that heavy metals of the ash will be immobilized to such an extent that it is environmentally acceptable to use bio ash in concrete. One purpose of the present LIFE supported project is by an extended test programme hopefully to confirm these promising preliminary results.

This project aims to demonstrate that bio ash can indeed feasibly be used in concrete irrespective of the point of view taken; concrete technology-wise, environmental-wise or economy-wise.

This is directly in line with the Sixth Community Environmental Action Programme calling for better waste management, sustainable production and consumption

patterns. With reference to the Sixth Environment Action Programme of the EU, the project will also contribute to clean technologies and reduction of greenhouse gases by the cement substitution, while reducing the amounts of waste (bio ash) for disposal.

The Partners in this project are two waste water treatment plants and a producer of ready mixed concrete:

Avedøre Wastewater Services. A cooperation among 10 municipalities operating 1 WWTP. Partner and the beneficiary for BioCrete. (AWS). This plant have a fluidised bed oven as the incinerator, and the bio ash has particle size characteristics like fly ash.

Lynettefællesskabet I/S. A cooperation among 8 municipalities operating 2 WWTP's: Lynetten and Damhusåen. Partner of BioCrete. (LYNIS) This plant has a conventional multiple hearth furnace, and the bio ash being a 'bottom'ash also include more coarse particles.

Unicon A/S. A company with a great number of concrete producing factories, e.g. Avedøre (close to the AWS WWTP), Ejby and Hedehusene. Partner of BioCrete. (UNICON)

Danish Technological Institute. The consultant for BioCrete (DTI)



Concrete trucks from Unicon

## **ACTIONS AND MEANS**

Before the project began, small scale tests had already demonstrated that it is possible to use bio ash concrete for limited purposes; but the actual use of bio ash in concrete was very limited. Unless more documentation of bio ash and bio ash concrete emerged it was unlikely that use of bio ash concrete in concrete would increase.

In order to provide the necessary documentation to overcome the barriers for extensive use of bio ash concrete, the project has been executed in two major phases:

1. Design, construction, implementation and use of systems required for full-scale production of bio ashes concrete – as these systems did not exist at the start of the project.
2. Tests in the laboratory and in the field of the properties of the bio ash and bio ash concrete in order to document that full scale production of bio ash concrete can take place without adverse effects on the final structures.

The full scale production test consisted of activities relating to the design and installation of outlets for dry bio ash at the incineration plants, the design and installation of bio ash handling facilities at the concrete plant, the delivery of bio ashes concrete to various construction sites in the Copenhagen area including extended testing and follow up on the execution experiences during casting of the concrete.

The laboratory tests of the bio ash and concrete included documentation of the chemical and physical properties of bio ash over a full production year, the leaching of heavy metals from bio ash concrete, the development of strength of bio ash concrete (including the consequences of the content of phosphate in the ashes), and the long-term durability of the bio ash concrete. Existing bio ash concrete structures was investigated to establish the field performance of bio ash concrete.

## **RESULTS – FULL SCALE PRODUCTION**

### **Design and construction of facilities for handling of ashes at the sludge incineration plant**

The full-scale handling facilities for the transfer of dry bio ash to powder transport truck are in full operation at the two Waste Water Treatment Plants (AWS and LYNIS). Both ash outlets were established and tested by February 2006. In the following months some final adjustments were being made as well as some finishing building works. Thus, both ash outlets have been integrated and are well functioning.



The bottom of the ash silo, the new screw conveyor and the load bellows at AWS.

However two serious problems were identified at the wastewater treatment plant Lynetten; The structure of the bio ash makes it difficult to transfer the bio ash from the dry powder transportation truck to the Unicon silo, and second, this structure with a particle size distribution with many coarse particles seems to make this bio ash less or little suitable for the production of concrete. The “transfer problem” was solved by installing a bow sieve with interior arms for moderate crushing/degrading of the ash between the ash silo and the screw conveyor. The diameters of the holes in the sieve are 10 mm. After this improvement no more difficulties were experienced with respect to the external transfer of bio ash.

Regarding the use of the ash produced in a plant with a conventional multiple hearth furnace it must be concluded that this type of ash has a particle distribution that makes it unsuitable to be used in concrete without further treatment. For the laboratory experiments, the a portion of the ash was grinded to a more suitable particle size. As changes are considered for the future sludge incineration at LYNIS , it has not been relevant to establish grinding at full scale.

It can be concluded that the type of incinerator is very important to the properties of the ash. Bio ash from a multiple hearth oven (LYNIS) is without pre-treatment less suitable for concrete production than bio ash from a fluidised bed oven (AWS).

### **Design and construction of facilities for handling of ashes at the concrete production plant**

Powder materials such as cement, fly ash, silica fume and bio ash must be handled in closed systems to prevent environmental problems. A screw conveyor brings the powder materials from the silos into the batch equipment from where it is delivered into the mixer by gravitation. The concrete production is controlled by a computer

system integrated with the dispatch and laboratory systems. Any change or any new material will therefore demand investments in the plant to secure that the processes are still in control and recorded.

The facilities for handling the ash at the concrete production plant were established from January 2006 till the end of June 2006 with the Avedøre (Stamholmen) plant being the first. The Hedehusene plant had already been using bio ash from an extra silo for a longer period. Finally, the Ejby plant was upgraded and was able to receive bio ash from end of July 2006.



Unloading bio ash at Unicon's plant in Avedøre.

The ash handling systems at the concrete production plants are in full operation and it must be concluded that the ash can be handled in normal powder handling systems at concrete plants i.e. conveyers weighing systems etc. It is necessary to have a silo only to be used for bio ash in order to avoid problems with unintended mixing with other materials.

### **White bio ash – ash production and concrete trial casting**

The reddish colour of bio ash concrete produced using the red bio ash has been identified as a significant barrier, when the concrete is to be used for visible materials and constructions, and especially when in combination with normal grey-coloured concrete. The red colour is due to iron compounds in the bio ash, and "white" (lighter) bio ash was produced at "Damhusåen WWTP" (part of LYNIS organisation) by substituting iron by aluminium for the precipitation of phosphorus during the wastewater treatment.

Damhusåen was operated for half a year using an aluminium precipitant (for the removal of phosphorus) instead of an iron precipitant, and afterwards to transfer 150 m<sup>3</sup> of sludge cake was incinerated at AWS (Avedøre WWTP), thus producing 10 t

of 'light bio ash' (or aluminium bio ash). The colour of this light bio ash is yellow-brownish and lighter than the 'normal' red bio ash (or iron bio ash). The colour of the bio ash is related to the iron content; however, not only to the total iron content, but definitely also to the structure and mineralogy of the ash. It seems very likely that the red colour is related to the content of haematite (crystalline  $\text{Fe}_2\text{O}_3$ ).

It has been noticed, that bio ash concrete has a reddish colour that is quite different from the grey colour of reference concrete. Further, it is the impression that the bio ash concrete colour becomes paler with time, especially if the slabs are placed outdoor. In the picture below there are shown concrete slabs with red and light bio ash (both with 85 kg/m<sup>3</sup> bio ash and no fly ash) as well as a reference slab (no bio ash and 70 kg/m<sup>3</sup> fly ash).



Concrete slabs with 1) no bio ash, 2) light bio ash and 3) red bio ash

As an ingredient in concrete mix designs, the light bio ash is technically just as good (or even a little better) than red bio ash, and much better with respect to the discolouring of bio ash concrete. The limit contents for no adverse colour effect seem to be 20 – 40 kg/m<sup>3</sup> for light bio ash and only 5 – 10 kg/m<sup>3</sup> for red bio ash.

European sludge incineration plants produce iron bio ash as well as aluminium bio ash. The choice of precipitant for the removal of phosphorus at the WWTP's depends on local process performance as well as economy. Iron is normally the choice in Denmark.

### **Production of bio ash concrete**

Unicon A/S has been using bio ash for production of concrete in the Copenhagen area since the beginning of 2003. From 2003 at plant-Hedehusene, from 2005 further at plants-Avedøre Holme and from 2006 also at plant-Ejby. Production of concrete with bio ash is only possible under the condition that supplementary/new silo facilities etc. are established.

Bio ash was used in strength classes 8 and 12 MPa according to DS/EN 206-1 “Passive environmental class” as well as for production of concrete not delivered according to DS/EN 206 (i.e. for concrete used for placing e.g. cobblestones and for concrete with a compressive strength lower than 8 MPa). Due to the reddish bieflect bio ash could not be used in higher strength classes which are used in “visible” constructions.

The existing information at Unicon has been compiled in terms of batch information and associated concrete test results from the past years delivery of bio ash concrete. The total production and consumption from the three plants was:

Bio ash consumption, Cph area		
Year	m <sup>3</sup> – concrete	Bioash, tons
2003	2.916	85
2004	6.674	221
2005	4.621	182
2006	13.117	928
2007	12.052	712
<b>Total</b>	<b>39.380</b>	<b>2128</b>

The mixes were originally designed, so that 50% of the fly ash in the mixes P08 and P12 were substituted with bio ash; Together the fly ash and the bio ash made half of the powder content in these mixes (in kg’s). The bio ash content was increased to 100% of cement content in kilos (“half and half”), i.e. no fly ash in the mixes P08 and P12.

This led to major problems on the consistency of the concrete, and the slump was much too low although the water content was very high compared to a similar concrete without bio ash, and superplastizer was added. Further, a decrease in the compressive strength level (7 days) was observed.

This led to the decision to change the mix design to the original, so that 50% of the fly ash in the mixes is substituted with bio ash. Concrete in Passive, Moderate, Aggressive and Extra Aggressive Environmental class has been pretested with a good result (50% bio ash).

The conclusions from full scale testing are:

- When the reference concrete and the concrete with bio ash are compared, there is no significant difference in the strength at 28 days for either 8 MPa or 12 MPa, when the fluctuation of the water/cement ratio is taken into account.

- There is no difference in the standard deviation for the reference concrete and the concrete with bio ash.
- Concrete with bio ash does not deviate from concrete without bio ash as concerns the mixing properties (i.e. dosage and ability of the air entraining agent to form air in the concrete).
- Concrete with bio ash demands more water than concrete without bio ash to achieve the same consistency. To maintain the strength level, there has to be added more cement (to retain the w/c ratio).
- There seems to be a lower increase in strength for 7 to 28 days for concrete with bio ash.
- Concrete for placing cobblestones (low slump concrete) is no longer produced with bio ash. The concrete does not reach the same strength level on the construction site, and is difficult to get out of the trucks.

### **Experiences from full scale production**

The results from the full scale production shows that it is possible to establish ash handling facilities at both the waste water treatment plants and the concrete production plants with no significant problems. The ash from the plant with the traditional heath furnace is too coarse to be used in concrete production without further treatment.

Concrete with bio ash has a reddish tint, which can be a problem when the concrete is used in visible constructions. It is possible to produce "light" bio ash, but the concrete still has a slight reddish nuance. The colour seems to fade over time when exposed to the environment. If only a small amount of bio ash is used (20 – 40 kg/m<sup>3</sup> for light bio ash and 5 – 10 kg/m<sup>3</sup> for red bio ash), the colour of the concrete is not affected.

When using bio ash in the concrete, the consistency of the concrete is affected. It is necessary to add more water and/or superplastizer to obtain the same consistency. When adding more water, the cement content has to be increased accordingly to maintain the water/cement ratio.

## **RESULTS – LABORATORY TESTS**

### **Documentation of the quality of the ashes**

In order for bio ash to be an accepted raw material for concrete production it must be documented that the ash can be produced with consistent physical and chemical properties.

To evaluate the uniformity of the ash production ash samples was collected from both the Lynetten plant and the Avedøre plant over a period of several months.

A total of 13 bio ash samples from the Lynetten and the Avedøre plants have been analysed in order to evaluate their chemical and physical properties in relation to their use as fly ash or cement replacement in concrete. The analyses have largely been performed according to the European standard for coal fly ash in concrete DS/EN 450-1.

#### Chemical properties:

- The chemical properties including the heavy metals content of the Lynetten and Avedøre bio ashes is fairly constant over an extended production period.
- The bio ashes have low content of the primary oxides  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  compared to coal fly ashes.
- The bio ashes from Lynetten have high loss of ignition, whereas the Avedøre ashes have low values.
- The bio ashes have generally very low reactive silicon content.
- The bio ashes all have a lower soluble phosphate than maximum limit in DS/EN 450-1.
- The chloride content of the Lynetten ashes is slightly higher than the maximum limit in DS/EN 450-1, but a factor 10 lower in the Avedøre ashes.
- The bio ashes have very similar mineralogical composition- determined by QXRD to be primarily amorphous materials (50-70%), calcium phosphate (8-21%), quartz (8-16%) and ironoxides. The Lynetten ashes having more amorphous material and less calcium phosphate than the Avedøre ashes.

#### Physical properties:

- The physical properties of the Lynetten and Avedøre bio ashes are fairly constant over an extended production period.
- The bio ash particles are generally very coarse grained compared to coal fly ash and Portland cement. They are irregular, angular and porous in structure.
- All bio ashes have 28 days activity indexes which are higher than the demand in DS/EN 450-1. The ashes from Lynetten also fulfil the 90 days demand but no increase in the index is observed from 28 to 90 days. The Avedøre ashes do not fulfil the 90-day demand in DS/EN 450-1.
- The density of the bio ashes is higher than that of coal fly ash and varies from 2700 to 2850  $\text{kg/m}^3$
- The setting time measured for the Lynetten ash samples are high and more than the 120 minutes longer than for the reference cement, i.e. not conforming to DS/EN 450-1. The Avedøre ashes fulfil the demands of DS/EN 450-1.

The obtained data suggests that the bio ashes investigated can only be expected to have minor pozzolanic effect if used as a cement replacement in concrete.

Based on their chemical and mineralogical composition the bio ashes are not expected to have specific negative effects on the durability of concrete.

Based on the particle size distribution, irregular shape and internal porosity the bio ashes are expected to influence the properties of fresh concrete. In particular the workability might be negatively affected.

It should be stressed that it is not a formal problem that the bio ashes do not conform to the fly ash standard DS/EN 450-1 as bio ash is not a fly ash after the definition in DS/EN 450-1. Bio ash can therefore still be used in concrete according to DS 2426 (the national application document for the European concrete standard EN 206).

### **Collecting data from existing bio ash concrete constructions**

Two structures have been inspected: The parts of the Green Bridge at Vejle in Jutland (constructed in 2002) made with bio ash and the "fill in" concrete in an underground sewage construction in connection with stormwater detention tanks constructed in 2004. It has not been possible to find older structures with bio ash concrete.

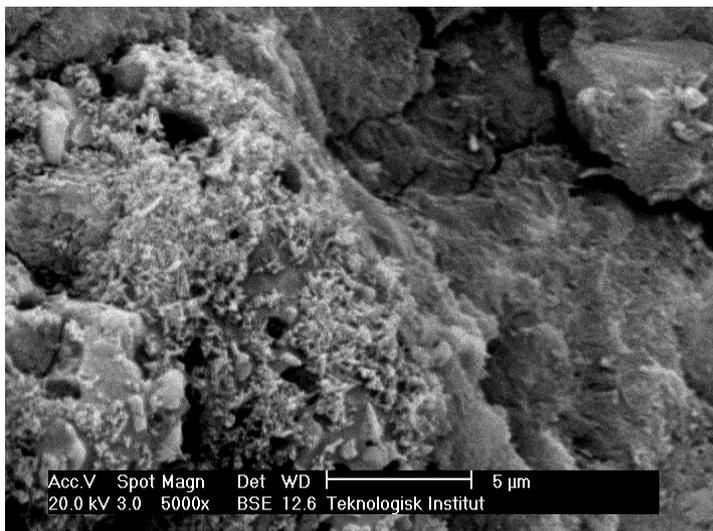
The bio ash concrete of the demonstration bridge shows all the signs of being a healthy durable concrete. The microstructure does not show any significant defect originating from the plastic or hardened state of the concrete, i.e. it is properly placed and cured concrete of adequate composition.

No evidence was obtained that the bio ash particles take part in hydration reactions or other chemical reactions in the cement paste.

The chloride penetration into the bio ash concrete is higher than expected. A possible reason is the fact that the bio ash concrete was cast on November 1st, 2002 at fairly low temperatures right before winter time, whereas the bridge deck etc. was cast in late March 2002. The bridge was put into service already on December 17th, 2002 meaning that the bio ash concrete compared to the bridge deck had significantly less maturity when first exposed to chloride ions, i.e. the bio ash concrete was not as dense as the bridge deck when first exposed to chloride.

The bio ash concrete of the water basin is generally in good condition and based on the microscopy analysis the compressive strength is estimated at around 20 MPa. The concrete has a high water to cement ratio, and areas of increased porosity due to short plastic cracks originating from the first few hours from placements are observed.

Observations in the scanning electron microscope do not suggest that bio ash particles have reacted at all within the cement paste, i.e. any strength contribution from the bio ash is most likely due a filler effect.



Scanning electron microscopy (SEM) showing the rough and irregular surface of a bio ash particle in concrete from water basin.

### Comparison between bio ash concrete and conventional concrete

The comparison is based on two investigations of concrete made with bio ash – a high strength concrete and a low strength concrete. Currently, both concretes perform well and exhibit properties that do not deviate significantly from comparable conventional concrete without bio ash.

As all Danish bio ash concrete the investigated concretes are still young, less than 5 years of age, and consequently it has not been possible to evaluate their long-term durability performance. However, there are no signs that the long-term durability will develop any different than expected for comparable conventional concrete.

### **Environmental impact of bio ash concrete**

The focus on the potential leaching from the concrete at the end of the lifecycle reflects the fact that concrete after demolition is going to be utilised as crushed materials for road construction or similar purposes. Currently, in Denmark 95% of all demolished concrete is used for road construction purposes. Even though the concrete recycling percentage may be lower in other parts of Europe, it is very likely that the rest Europe will obtain higher reuse rates of demolished concrete in the future.

The environmental impact of bio ash concrete is evaluated using a method of characterization (defining 3 categories of residues) described in the Danish ministerial order No. 1635 of 13. December 2006 "Recycling of residues and soil for construction works" and comparing with a similar characterization of a reference concrete with no bio ash.

Thus, according to the ministerial order, the present characterization is based upon a European leaching test method prEN 12457-3 (June 1998), and the leachate has been analyzed for 19 heavy metals: Ag, As, Ba, Bi, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni,

Pb, Sb, Se, Sn, Tl, V, Zn, and in the ministerial Order the underlined 10 metals are attributed with leachate limit values which define residue category.

Further, in order to simulate behaviour of fresh (i.e. not carbonated) as well as aged (i.e. carbonated) concrete, the concrete samples have been tested after no exposure to carbon dioxide as well as after 1 – 2 months of exposure to carbon dioxide.

In this way 6 different bio ash concrete samples have been tested, and in total 20 leachates have been analyzed.

Comparison between bio ash concrete and reference concrete: For all heavy metals and for not carbonated as well as carbonated concrete samples there is no significant difference between the concentrations in the bio ash concrete leachate and the reference concrete leachate. This is the case although the concentration of some heavy metals (Bi, Cu, Hg, Pb, Se and Zn) is approximately ten times higher in bio ash as in cement and as in fly ash.

Category characterization (category 1 is the best): No metal exceeds category 3. Chromium (Cr) corresponds to category 3. Barium (Ba) also corresponds to category 3 if the concrete sample is not carbonated, but to category 1 when carbonated. Mercury (Hg) probably corresponds to category 1, but the analytical detection limit was too high in order to be sure. The remainder 7 metals correspond to category 1.

Thus, because of chromium (and barium) the bio ash concrete corresponds to a category 3 residue – but the same is the case for the reference concrete!

Two leaching tests (bio ash + reference) according to a Dutch Standard method show leachate heavy metal concentrations far below the category 1 limit values.

The overall conclusion is that the use of bio ash for concrete production has very limited environmental impact.

### **Technical documentation of bio ash concrete**

In terms of traditional concrete technology a few concerns have been raised in connection with the use of bio ash concrete. To use bio ash concrete in other more aggressive environment more documentation is required primarily on long-term durability and strength development, in particular the role played by the high content of P<sub>2</sub>O<sub>5</sub> in the bio ash.

A total of 6 samples of bio ash has been evaluated, 3 samples each from Avedøre (AWS) and Lynetten (LYNIS). The ash from LYNIS was milled to a finer particle size distribution before the mixing.

There were only minor variations in the results from the freeze-thaw tests between the different ashes including the reference. All samples fulfilled the requirements of DS-EN 206-1 and DS 2426.

The effect of the different bio ashes on the shrinkage of concrete was evaluated according to the principles in DS 434.6. In general there were very small differences between the results of the different concrete samples including the reference, although the shrinkage of the concrete samples cast with bio ash was slightly higher than that of the reference.

The heat development measurements have been performed through semi-adiabatic Hay-box calorimetry. The total heat development of the bio ash concrete mixes is comparable to that of typical reference concrete mixes with fly ash. The heat development measurements indicate that the setting time for the bio ash concrete mixes are higher than that of concrete mixes with fly ash, but once the setting starts the heat development is slightly more rapid. There is no indication that the content of  $P_2O_5$  has any influence on the results.

In general the compressive strength measurements showed no significant differences between the different bio ashes and the reference.

Overall the concrete mixes had similar properties regarding durability and strength development, with the only major difference being the later setting time indicated in the heat development test. It was possible to obtain satisfactory fresh concrete properties with both types of bio ash, although the mix designs had to be modified to compensate for the bio ashes higher water demand. All concrete mixes were modified with higher paste content and/or higher super plasticizer dosage and a 50-50 percent mix of fly ash and bio ash, in order to obtain satisfactory fresh concrete properties.

### **Experiences from laboratory tests**

The overall conclusion of the laboratory tests of the ashes, the concrete, the environmental impact and the existing constructions is that the properties of concrete with bio ash is comparable to "ordinary" concrete.

### **RECOMMENDATIONS**

This project has shown that using bio ash in concrete is possible. There are some considerations regarding the consistency of concrete, which leads to a slightly higher amount of cement. From an environmental point of view it can be discussed whether this is preferred compared to disposal of the ashes.

From a concrete point of view, the results shows that care should be taken when deciding the ratio of bio ash to fly ash. If there is too much bio ash there is a risk of loss of early strength. There's no indication that the variation of the amount of  $P_2O_5$  in the ash plays a role regarding the setting time. The investigations of the existing, but not very old constructions show no difference in durability compared to concrete without bio ash.

When using bio ash the concrete has a slight reddish colour, this can be a constraint when used in visible constructions. To avoid this, either use a smaller amount of ash in the concrete or use the lighter coloured ash.

The economical conditions in Denmark regarding taxes mean that it is economically a good idea to use bio ash in concrete.