The reuse of bio ash for the production of concrete. A Danish case study

D. Kjersgaard*, B. N. Jacobsen*, K. Rindel**, L. Andreasen***, F. Larsen***, P. Nyegaard****, C. Pade****, J. Bodker****

* Avedoere Wastewater Services, Kanalholmen 28, DK-2650 Hvidovre, Denmark
(E-mail: *dk@spvand.dk*; *bnj@spvand.dk*)
** Lynettefaellesskabet, Refshalevej 250, DK-1432 Copenhagen K, Denmark
(E-mail: *kr@lyn-is.dk*)
*** Unicon Ltd., Islands Brygge 43, Postbox 1978, DK-2300 Copenhagen S, Denmark
(E-mail: *la@unicon.dk*; *flar@unicon.dk*)
**** Danish Technological Institute, Gregersensvej, DK-2630 Taastrup, Denmark
(E-mail: *pernille.nyegaard@teknologisk.dk*; *claus.pade@teknologisk.dk*; *jorn.bodker@teknologisk.dk*)

Abstract. BioCrete is an ongoing project supported by the EU-LIFE Environment programme. The purpose of the project is to facilitate and increase the reuse of bio ash (= sludge ash) for the production of concrete. Convenient equipment for the handling of dry bio ash has been installed at two Danish wastewater treatment plants and at 3 ready-mixed concrete production plants, and 1100 tons of bio ash was reused for the production of concrete in 2006. The used bio ash is produced in a fluid bed incinerator oven. Bio ash from a multiple hearth oven could not be used for concrete production because of a content of bigger particles. Bio ash is mainly used as a partly substitution for fly ash in concrete recipes, and 50% seems to be a maximum. A thorough analytical characterization of bio ash has been carried out and compared with data for ordinary fly ash, i.e. ash from coal fired power plants. Bio ash and fly ash are quite different materials and bio ash has less pozzolanic effect than fly ash. Aluminium based bio ash seems to be better for the production of concrete than iron based bio ash with respect to colour as well as strength.
Keywords. bio ash; concrete; EU-LIFE project; fly ash; reuse; sludge ash

INTRODUCTION

It is a continual concern for urban wastewater treatment plants (WWTP) to adjust and optimize the handling and disposal of the produced solid waste: the sludge, or with the terminology of this conference: the biosolids. In Europe, an increasing part of the produced sludge is incinerated, especially at bigger cities, where available farm land disposal sites for sludge are far away. The normal way for the disposal of the produced sludge ash is transfer wetted sludge ash to controlled land fill sites. One possibility for the reuse of the sludge ash is to use the dry sludge ash as an ingredient for the production of concrete.

This possibility is inspired by the fact that *fly ash*, i.e. the ash from coal fired power plants, has been used for many years as a valuable constituent in concrete production recipes. Therefore, it is a hope that sludge ash can be used as a substitute for fly ash in various concrete recipes.

The use of sludge ash has earlier been studied in Denmark in connection with the project "Green Concrete" [1]. The results were quite promising, and for the past years some full scale bio ash concrete has been produced. In very limited amounts, however, because of lack of proper handling facilities for dry sludge ash at the WWTPs and the ready-mixed concrete production plants, as well as lack of documentation of the technical and environmental properties of bio ash concrete. For the time being, the use of bio ash concrete is only permitted on a temporary basis.

Thus, 3 Danish partners (see below) decided to define a new demonstration project, which hopefully would ease the future reuse of sludge ash for the production of concrete by improving the handling facilities and the available documentation. The driving force for the partners engagement in this project is to find a sustainable method of sludge ash reuse, which is acceptable for the environment and which eventually also could reduce the operation costs for the partners. If the bio ash reused, e.g. for the production of concrete, a governmental fee for land fill of waste (50 €/ton in Denmark) is not to be paid.

The project has been granted financial support by the European Union LIFE Environment programme, a support amounting to a maximum of 50% of the budgeted project costs. In this project we use the word *bio ash* in stead of sludge ash, and the project acronym is *BioCrete*. The project period is June 2005 to December 2007, and the purpose of this paper and presentation is to disseminate some of the recent project results. Further information can be found on the project home page: http://www.biocrete.dk [2].

THE BIOCRETE PROJECT PARTNERS

The following 3 partners have signed an agreement with the Danish Technological Institute to act as a consultant for the project, thus supplying tests and analytical work as well as a number of disseminating and administrative activities.

Avedoere Wastewater Services

A WWTP serving 10 municipalities in the western part of Copenhagen. The amount of wastewater is approx. 25 mio. m^3 per year, and the treatment consists of 'normal' mechanical, biological and chemical steps, the latter using iron ($FeClSO_4$) as precipitant for phosphorus removal. The sludge is digested (mesophilic), dewatered on decanter centrifuges, the sludge cake is up to a point dried and finally incinerated in a <u>fluid bed</u> oven. The production of bio ash is approx. 2200 tonnes per year. Home page: http://www.spildevandscenter.dk.

Lynettefaellesskabet

Two WWTPs serving the central part of Copenhagen: Lynetten WWTP receiving approx. 60 mio. m^3 per year of wastewater and Damhusaaen WWTP receiving approx. 25 mio. m^3 per year. The treatment steps are for both WWTPs very similar to the ones mentioned for Avedoere WWTP, but only until the production of sludge cake. The sludge cake from Damhusaaen WWTP is transferred to Lynetten WWTP, where it together with the Lynetten sludge cake is incinerated in a <u>multiple hearth</u> oven. The production of bio ash is approx. 5600 tonnes per year. Home page: http://www.lyn-is.dk.

Unicon

The biggest producer of ready-mixed concrete in Scandinavia, with approx. 50 production plants situated in Denmark. Home page: http://www.unicon.dk.

RESULTS AND DISCUSSION

Installation of full scale equipment

The first phase of the project was to establish convenient equipment for a dust free handling of dry bio ash at Avedoere WWTP and Lynetten WWTP with transfer facilities to dry powder transportation vans. This has been completed, and the equipment functions very well. At Unicon, upgraded electronic equipment for the reception and recording of bio ash has been installed at 3 ready-mixed concrete production plants in the greater Copenhagen area.

Analytical characterization of bio ash

During 2006 six samples (each of 200 kg) of bio ash has been collected at both WWTPs and sent to the Concrete Centre Department at the Danish Technological Institute for analysis and testing.

The bio ash from Lynetten WWTP. It was not possible for Unicon to produce concrete with the actual quality of this bio ash from a multiple hearth incinerator. The reason is expected to be the content of rather coarse slag-like particles. Therefore is has been decided to pre-treat this bio ash by grinding and postpone further analytical work and testing until a proper pre-treatment has been carried out. *In this paper, therefore, only data for the fluid bed incinerator bio ash from Avedoere WWTP will be presented and discussed.*

Because bio ash is expected to become a substitute for fly ash in concrete recipes, an important part of the analytical programme is a characterization according to the parameters defined in the European Standard EN 450-1 for Fly ash [3].

Chemical parameters. In table 1, the result of the analysis of the 6 samples from Avedoere WWTP is shown as the range of values, and for comparison also a typical value for fly ash is shown. An additional parameter showing the total content of phosphorus (as P_2O_5) is included (analyzed by WDXRF = Wavelength Dispersive X-ray fluorescence spectrometry).

Table 1. Bio ash characterization. 6 samples from a fluid bed incinerator.
Chemical parameters, cf. EN 450-1:2005, section 5.2

Analytical parameter			Bio ash	Fly ash for concrete	
Name	Unit	Method	Range	Typical value	Requirement
Loss on ignition (950 ^{0}C)	%	EN 196-2	1.5 - 2	2.1	< 5 (Category A)
Soluble phosphate	mg/kg*	Annex C*	70 - 85	27	< 100
Phosphorus as P_2O_5	%	WDXRF	26 - 27	0.3	
Silicon dioxide (SiO_2)	%	EN 196-2	21 - 24	51	
Reactive silicon dioxide (SiO_2)	%	EN 197-1	11 - 13	36	> 25
Free calcium oxide (CaO)	%	EN 451-1	< 0.01	0.4	< 2.5
Calcium oxide (CaO)	%	EN 196-2	19 - 20	7.1	
Iron oxide (Fe_2O_3)	%	EN 196-2	14 - 16	8	
Aluminium oxide (Al_2O_3)	%	EN 196-2	6.2 - 6.8	22	
Sum of SiO_2, Al_2O_3 & Fe_2O_3	%	EN 196-2	42 - 47	81	> 70
Magnesium oxide (MgO)	%	EN 196-2	3.0 - 3.1	2.5	< 4.0
Sulfuric anhydride (SO_3)	%	EN 196-2	1.3 - 1.7	1,1	< 3.0
Chloride (Cl^-)	%	EN 196-21	< 0.02	0.015	< 0.10
Total content of alkalis (as Na_2O)	%	EN 196-21	1.0 - 1.2	2.3	< 5.0

* Annex C in EN-450-1:2005; the analysis expresses mg "available phosphorus pentoxide" (P_2O_5) per kg ash

There are big differences between bio ash and fly ash. Bio ash contain much more phosphorus and also calcium, while the content of silicon and reactive silicon is much lower and not fulfilling the requirement set for fly ash.

Physical parameters. In table 2, which has a similar layout as table 1, data for a number of physical parameters are shown.

Table 2. Bio ash characterization. 6 samples from a fluid bed incinerator.
Physical parameters, cf. EN-450-1:2005, section 5.3

Analytical parameter			Bio ash	Fly ash for concrete	
Name	Unit	Method	Range	Typical value	Requirement
Activity index, 28 days	%	EN 196-1	76 - 81	85 - 90	> 75
Activity index, 90 days	%	EN 196-1	83 - 85	95 - 110	> 85
Water requirement (consistence)	g/100g	EN 196-3	32 - 33	26 - 29	
Initial setting time	min	EN 196-3	255 - 300	140 - 240	
Increase of Initial setting time	min	EN 196-3	70 - 115	30 - 60	< 120
Soundness (expansion)	mm	EN 196-3	0 - 1	0 - 1	< 10
Fineness (> 45 μm)	%	EN 451-2	58 - 63	< 30	< 40 (Category N)
Fineness (> 125 μm)	%	*)	37 - 45	< 5	
Particle density	kg/m^3	EN 196-6	2790 - 2850	2200 - 2300	+/- 200

*) Determined by wet sifting and as a pretreatment for determination of particle size distribution of the fraction < 125 μm

The activity index is an indicator of the compressive strength of standard mortar bars poured with specified quantities of ash. The bio ash just fulfils the fly ash requirement, but is less efficient than fly ash. Further, it is noted that bio ash has a higher water requirement, a longer setting time, bigger particle sizes and a higher particle density than fly ash.

Electron microscopy shows a big difference between bio ash and fly ash, see figure 1 and 2. The fly ash consists of spherical particles, while the bio ash consists of edged particles and porous material. This might explain the higher water requirement. The differences are probably due to the different chemical and mineralogical composition of the ashes as well as the different incineration temperatures (1300 ^{0}C for fly ash and 850 ^{0}C for bio ash).

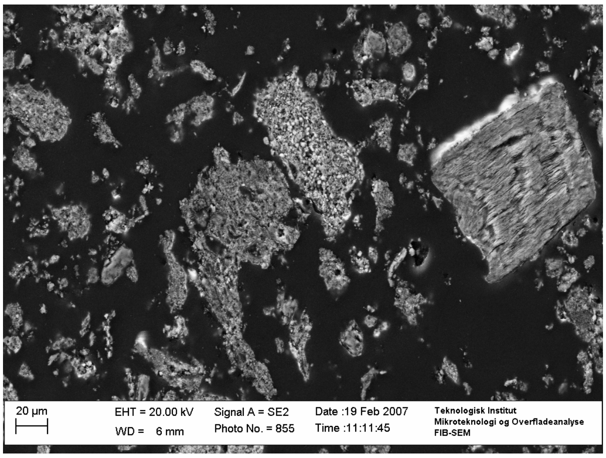

Figure 1. Microscopic picture of bio ash (the big particle size is approx. 120 μm)

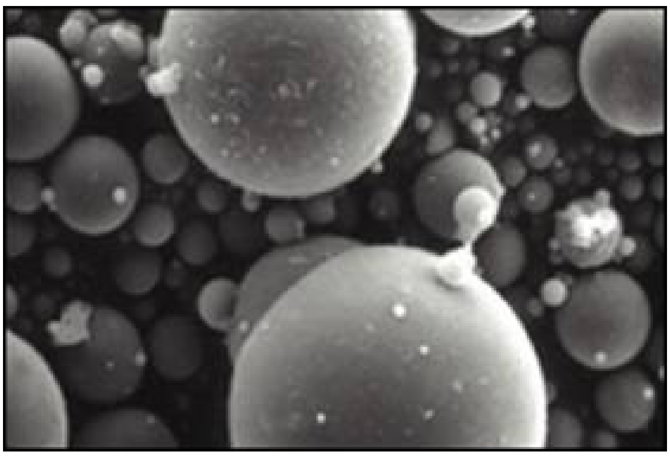

Figure 2. Microscopic picture of fly ash (the diameter of the bigger balls is approx. 50 μm)

Mineralogical parameters. An analysis of the mineralogical phases of bio ash by Quantitative X-ray Diffraction (QXRD) shows only 50 – 60% amorphous phase, approx. 20% of calcium phosphate, 10% of quartz, 6% of haematite and a.o. gypsum in smaller quantities. For a typical fly ash the composition is 80% amorphous phase, 11% mullite and 6% quartz.

The presence of amorphous phase as well as reactive silicon dioxide is important for the *pozzolanic* effect of the ash, i.e. the cement-like ability to produce an 'inorganic glue' of various hydrated calcium silicates.

'Light bio ash'
The colour of bio ash is reddish while fly ash is greyish. The reason is that the iron content is higher in bio ash, cf. table 1, and that the iron in bio ash partly is present as the red haematite (crystalline Fe_2O_3). Thus, bio ash concrete has a slight reddish colour, quite pleasant - but, unlike the greyish and more cold colour of fly ash concrete. Therefore bio ash concrete can not be used for visible structures where you also use batches of 'normal' concrete.

As a consequence, Unicon suggested to include an activity in the project, where the bio ash originates form a WWTP using aluminium in stead of iron for the precipitation of phosphorus. This was done at Damhusaaen WWTP, where the normal iron precipitant was replaced by an aluminium precipitant for six months (February – August 2006), thus assuring the production of representative 'aluminium sludge' (more than 3 sludge ages had passed through the WWTP). After that, 150 m^3 of aluminium sludge cake was transferred to be incinerated as a separate batch at Avedoere WWTP. In this way approx. 11 tons of 'light bio ash' was produced.

Table 3. Bio ash characterization. Samples from a fluid bed incinerator.
Comparison of bio ash from two WWTPs precipitating P by Fe and Al, respectively.
Shown are parameters for which there is a significant difference between the 2 types of bio ash.

Analytical parameter			Bio ash	
Name	Unit	Method	Iron (Fe)	Aluminium (Al)
Colour			reddish	light brownish
Soluble phosphate	mg/kg*	Annex C*	75	30
Silicon dioxide (SiO_2)	%	EN 196-2	23	35
Reactive silicon dioxide (SiO_2)	%	EN 197-1	12	15
Calcium oxide (CaO)	%	EN 196-2	20	16
Iron oxide (Fe_2O_3)	%	EN 196-2	15	6,5
Aluminium oxide (Al_2O_3)	%	EN 196-2	6.5	13
Sum of SiO_2, Al_2O_3 & Fe_2O_3	%	EN 196-2	45	54
Phosphorus as P_2O_5	%	WDXRF	27	22
Calcium as CaO	%	WDXRF	21	16
Silicon as SiO_2	%	WDXRF	21	29
Amorphous	%	QXRD	55	63
Calcium phosphate	%	QXRD	19	14
Quartz (crystalline SiO_2)	%	QXRD	10	15
Haematite (crystalline Fe_2O_3)	%	QXRD	6	< 1
Particle density	kg/m^3	EN 196-6	2820	2640

* Annex C in EN-450-1:2005; the analysis expresses mg "available phosphorus pentoxide" (P_2O_5) per kg ash

In table 3 is shown analytical data for this aluminium based bio ash and compared with the data for the more common (in Denmark) iron based bio ash.

The result was very satisfactory. The colour of the aluminium based bio ash was indeed much lighter, and for the human eye the colour of aluminium bio ash concrete slabs is not different from the colour of slabs without bio ash.

The other parameters for which some difference has been identified between the two types of bio ash almost all seem favourable for the aluminium bio ash with respect to the production of concrete. Especially the much lower content of haematite is significant.

The production of bio ash concrete

Unicon has during 2006 included the possibility of using bio ash as an ingredient in the daily production of concrete at 3 plants, and the testing of the bio ash concrete has followed the normal procedures. In table 4 some production average data are shown.

Table 4. Concrete production data from 2003 - 2006

Data for the production of 8 MPa and 12 MPa concrete.

Average values for bio ash concrete and reference concrete

	Unit	Bio ash concrete	Reference concrete
8 MPa concrete			
Cement (C)	kg/m^3	114	101
Fly ash	% of C	75	100
Bio ash	% of C	33	0
Water	% of eqC*	97	100
Compressive strength 28 d	MPa	12	10
12 MPa concrete			
Cement (C)	kg/m^3	148	138
Fly ash	% of C	50	66
Bio ash	% of C	22	0
Water	% of eqC*	82	86
Compressive strength 28 d	MPa	17	16

* eqC = equivalent cement,
calculated using an activity factor of 0.5 for fly ash as well as bio ash

Thus, it is possible to produce bio ash concrete with a satisfactory quality according to the factory standard quality requirements. So far, only concrete of the lower strength classes (8 and 12 MPa) has been produced. As a substitute for fly ash, less than 50 % can be replaced by bio ash. In general, it is noted that bio ash does increase the water requirement, and it is necessary to add some extra cement.

The limited number of production data for aluminium bio ash concrete indicate that the strength of aluminium bio ash concrete is a little better than the iron ditto.

During 2006 Unicon has reused 1100 tons of bio ash (all from Avedoere WWTP) for the production of bio ash concrete.

Technical and environmental properties of bio ash concrete

The BioCrete Project includes activities for further technical documentation of bio ash concrete in a number of 'higher' classes. These activities have just started.

A potential environmental risk linked to the use of bio ash concrete is the eventual leaching of heavy metals to the environment (e.g. the soil), and this activity is also included in the Project, but has not yet started. However, some information is already available. The Danish Technological Institute has been involved in another project including leaching tests on sludge ash concrete, and this has been reported in 2006 [4]. The general conclusion is, that leaching of heavy metals is not a serious problem, and that the degree of leaching is very much dependent on which element and whether the concrete is carbonated or not.

CONCLUSIONS

Using bio ash as a substituting ingredient for fly ash in concrete production recipes has been demonstrated to be an acceptable possibility. So far concrete of lower strength, e.g. classes 8 MPa and 12 MPa have been produced. The content of bio ash in the concrete is typically 1.5 – 3 weight %, and in general it is not possible to substitute more than 50% of the fly ash by bio ash.

Bio ash and fly ash are quite different materials, as shown by the chemical, physical and mineralogical characterization as well as electron microscopy. Bio ash has less pozzolanic properties than fly ash, and the advantage of using bio ash can probably mainly be attributed to a good function as a filler in the concrete recipes.

REFERENCES

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