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Bio ash in concrete - a guideline

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Bio ash in concrete – a guideline

Bio ash can be used in concrete with good results:

- The ash can be handled at the wastewater treatment plant and at the ready mix concrete producer with the same equipment as other powder materials. There is no negative influence on the working environment, because the ash is handled in a closed system.
- Full scale trials show that the ash can replace a part of the fly ash. The best results is achieved when changing 50 weight % of fly ash with bio ash.
- Tests show the same low risk of leaching heavy metals as comparable concrete without bio ash.
- Inspection of a bridge constructed in 2002 shows no indications that concrete with bio ash is less durable than “normal” concrete.
- This is substantiated with laboratory tests, which show comparable results for concrete with and without bio ash.
- When bio ash is used in concrete, the colour of the concrete is slightly reddish. If a construction is cast with both types of concrete (with and without bio ash), the difference in colour can be a problem. However the colour seems to fade with time, and especially when exposed to the weather.

This guideline is based on the results from a 2½ year project called BioCrete. The project is supported by EU/life. 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. The partners in the project are two waste water treatment plants and a producer of ready mixed concrete: Avedøre Wastewater Services, Lynettefællesskabet I/S and Unicon A/S- and the Danish Technological Institute are consultants. The project period was from June 2005 to December 2007.

The guideline is meant as a help and inspiration for waste water treatment plants, producers of ready mix concrete and building owner.

Before: Dumping bio ash as a waste at the land fill site

The better use of bio ash: as valuable resource in concrete.

The conditions for the recommendations and results in this guideline

An important parameter regarding the quality of the ashes is the type of incinerator used at the waste water treatment plant (WWTP). The two WWTS's participating in the project has different furnaces. Avedøre Wastewater Services (AWS) has a fluidbed oven and Lynettefællesskabet I/S (LYNIS) has a multiple hearth furnace. This has a big influence on the particle size distribution, and ash from the multiple hearth furnace is much coarser than the ash from the fluidbed. The coarse ash can only be used in concrete with further treatment e.g. grinding. Tests of the other properties show no significance between ash from the two types of incinerator.

In the full scale production, ash from the fluidbed oven has been used and the experience from the production of concrete is therefore based on this type of ash. All the mixes contain coal fly ash, which is typical in Denmark. This is not necessarily the case in other counties, where other types of filler/powder is used, for instance limestone filler.

In Denmark, general suitability for bio ash in concrete in the exposure classes X0 and XC1 is established through the national document DS 2426. The ash shall be delivered with a declaration, containing certain parameters determined by the methods in EN 450-1 "Fly ash for concrete". If the ash is to be used in other countries, suitability shall be established.

Specifications of ash

Production of ash

Bio ash comes from sludge, which is produced in wastewater treatment. The sludge goes through a comprehensive process, before it is incinerated, and either deposited or transported to the ready mix concrete producer.

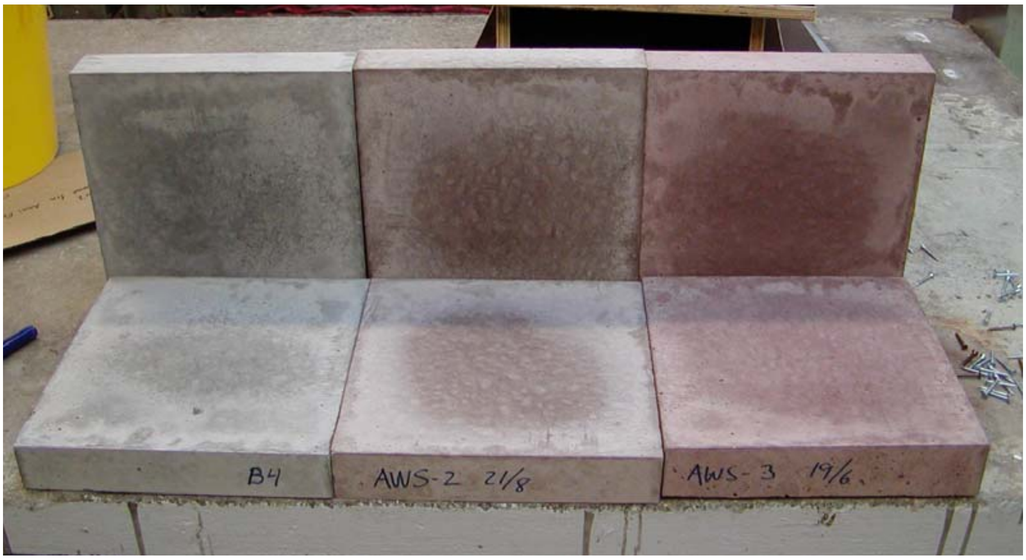
Incineration plant and aerobic digester at Avedøre Wastewater Services.   New bio ash outlet at Lynetten WWTP

For a given case, the process of producing the bio ash should be described briefly, as for instance like below for the process at Avedøre Wastewater Services:

1. A mix of primary sludge and biological excess sludge is fed to an anaerobic digester. During the process, biogas is produced and used for electricity- and heat production.
2. The digested sludge is dewatered in centrifuges, and dried to a content of dry matter of 32%. Then the sludge is transported to the fluidbed oven, where it is incinerated at a temperature of 850 °C. After at least 2 seconds in the oven, the flue gas and particles are let to further treatment.
3. In the flue gas purification facilities ash and particles are removed in the electrofilter, the gas is cooled and chemicals are added to bind smell, dioxin and heavy metals, especially mercury.
4. The bag filter separates the rest of particles in the gas, and the particles are sent to the ash silo. In scrubbers hydrochloric acid and SO2 is washed out of the flue gas. The gas is then heated to 115 °C and emitted by the 50 meter high chimney.
5. The ash is transported to the treatment plants own environmentally approved landfill or transported to the concrete producer.

Bio ash was a reddish colour, witch 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 Fe_2O_3). If aluminium is used for the precipitation of phosphorus during the wastewater treatment instead of iron, the produced ash has a lighter colour. As an experiment aluminium was used at “Damhusåen WWTP” (part of LYNIS organisation) in half a year, producing 10 tonnes of “light” bio ash 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).

In the picture below there are shown concrete slabs with red and light bio ash (both with 85 kg/m^3 bio ash and no fly ash) as well as a reference slab (no bio ash and 70 kg/m^3 fly ash).



Concrete slabs with 1) no bio ash, 2) light bio ash and 3) red bio ash with high dosage (85 kg/m^3)

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^3 for light bio ash and only 5 – 10 kg/m^3 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 waste water treatment plants depends on local process performance as well as economy. Iron is normally the choice in Denmark.

Establishing limit values for bio ash

Some of the significant parameters regarding the applicability of the ash in concrete are the chemical composition, the content off heavy metals and the physical properties as in EN 450-1 section 5 excluding the activity index and volume stability, but including water requirement. Since the temperature when incinerating the sludge and the type of incinerator has influence on the chemical and physical parameters, this aspect should also be considered when specification of the ash is decided. Incinerators in EU are regulated by a directive regarding waste incineration, where combustion at minimum 850 °C in minimum 2 seconds is prescribed.

When ash from a new source is assessed, it is recommended to perform tests regarding the parameters listed in the following. In cases where the documentation of the parameters exists, as for AWS and LYNIS, the regular control is adjusted on the basis of the known variation of the ash. It is recommended that these aspects are described in the agreement between the WWTP and the concrete producer.

The examples below are based on the ash originating from AWS For ash from other plants, the limits should reflect the known “normal-levels” and the values in the ash used for testing. For ash from AWS, the values are fairly stable during the year and the control of the ash can be done each quarter (as described in the Danish standard DS 2426).

Chemical composition:
If the chemical composition differs from the "normal level" the ash should not be used in concrete without further testing, as the effect on concrete durability is uncertain. Suggested limits are:

Parameter	***Method***	***Normal-level***	***Limit***
SiO_2	WDXRF	20 - 21 %	$\geq$ 18 %
CaO	WDXRF	20 - 23 %	> 18 %
P_2O_5	WDXRF	25 – 27 %	< 30 %
Fe_2O_3	WDXRF	15 – 17 %	13 – 20 %
Al_2O_3	WDXRF	6 - 7 %	4 – 8 %
MgO	WDXRF	2.8 – 3.4 %	< 4.0 %
K_2O	DS/EN 196-2	0.5 – 1.1 %	< 1.5 %
Na_2O	DS/EN 196-2	0.7 – 0.8 %	< 1 %
SO_3	DS/EN 196-2	1.2 – 1.8 %	< 3 %
Free CaO	DS/EN 451-1	< 0,01 %	< 2.5 %
Cloride	DS/EN 196-2	0.008 – 0.021 %	< 0.05 %

If the results do not comply with the recommendations, the concrete producer should be informed immediately, and it should be decided which supplementary tests are necessary.

Content of heavy metals:
If the content of one or more heavy metals differs from the "normal-level" the ash should not be used in concrete without further testing, as environmental impact is uncertain. The following suggestions regarding the limits of the ash are based on the results from the project, where the concrete can be used in category 3 (Danish ministerial order No. 1635 of 13. December 2006 "Recycling of residues and soil for construction works").

Parameter	***Normal-level***	***Results from leaching tests [1)]***	***Limit [1)]***
As	15 - 17	12.5	< 20
Ba		960	< 1200
Cd	4 - 7	5.4	< 10
Cr	40 - 190	64	< 200
Cu	520 - 860	790	< 1000
Hg	1 - 19	11	< 20
Mn	600 - 900	680	< 1500
Ni	50 - 100	62	< 150
Pb	100 - 150	170	< 200
Zn	1400 - 2100	1800	< 2500

The unit is mg/ kg ash, corresponding to mg / kg dry matter.
1) Test method UT012, which is equivalent to Danish Standard method DS 259. The samples are dissolved in semi-concentrated nitric acid at 120 ˚C in 30 minutes followed by an analysis on ICP-AES.

If the results do not comply with the recommendations, the concrete producer and the environmental authorities should be informed immediately, and it should be decided which supplementary test are necessary.

Physical parameters:
The density of bio ash should be declared to a value ± 100 kg/m^3 and the loss on ignition (EN 196-2) should not exceed 2.5 %.

The increase in setting time (EN 196-3) shall be less than 120 minutes more than the reference. The water requirement relative to a reference shall not exceed 120 % of the water requirement of the reference.

Production

Guideline on how to handle ash

Basically, an ash type with similar characteristics and qualities as type from AWS with fluid bed oven can be handled like other more traditional additions and binders for production of concrete. Ash from multiple hearth furnace like the type at LYNIS shall probably be grinded before used to concrete production.

Generally, however, you must pay attention to the fact that deposited ash cannot be used for production of concrete, because it has been moistened both prior to and during depositing. Thus, the ash must be supplied directly from the silo in dry condition.

Normally, sewage installations have no facilities for supplying directly into the tank truck. It is therefore a premise that facilities for delivering dry ash in closed systems are established. Such systems were established by AWS and LYNIS in connection with the present project. These facilities was well functioned and secured a suitable working environment at the loading place. If such facilities do not exist, collection can be very difficult. Practically, it is also required that the ash is completely dry, homogeneous and without lumps.

Transport from the sewage installation to the unloading into the silo at the concrete plant can follow by traditional, pneumatic powder-transporter like e.g. a “cement truck”.

Unloading and storage at the concrete plant must follow in a closed system to avoid the ash being moistened and to ensure an appropriate working environment at the plant.

Transport from the storage silo to the weighing system and further into the mixer can follow the exact same procedures as for other traditional additives and binders.

No working environmental risks exist, since we are dealing with closed systems, but naturally it must be ensured that a Material Safety Data Sheet is available.

Concrete mix (volume, colour, air and plastic) experiences and recommendations

Basically, bio ash is part of the concrete just like other pozzolanic additions and thus it contributes to the properties and performance of the hardened and fresh concrete. The activity index is, however, lower than for fly ash.

Aesthetically, you have to understand that a side effect of adding bio ash is a more or less reddish and warm colour (compared with a corresponding grey concrete).

As to the properties and performance of the fresh concrete, bio ash affects the concrete’s water need, and the concrete will - all other things constant – be more stiffer and less workable. This side effect can be prevented by adding extra water, cement and/or an increased quantity of plasticizing agents.

Adding bio ash affects the air content of the fresh concrete and the quantity of air admixtures should therefore be adjusted upon initial testing.

Adding bio ash can increase the spread as to the concrete's compressive strength, most likely because bio ash is still a new product being tested and therefore it is not yet as uniform as traditional concrete constituents.

Our project experience shows that bio ash can be physically and successfully added to all plastic concrete types within the range from concrete type 8 to 40 MPa if the following rules are observed:

- An optimal mix is achieved by replacing approx. 50% of the fly ash by bio ash.
- The concrete water requirements are increased depending on the quantity of bio ash. For example, 50 kg bio ash /m^3 will increase the water requirements by approx. 10%. Subject to the W/C-ratio, an increased volume of water must be compensated for by means of an equal volume of cement. Part of the increased water requirements can be compensated for by means of superplastification within the range of 0.5 % of the cement volume.
- The air content of the fresh concrete must be observed closely until adequate experience has been gained.

Bio ash should only be part of plastic concrete and not earth moist concrete, because problems regarding lack of compressive strength may arise.

Production (strength, consistence, mixing time) experiences and recommendations

During production concrete with bio ash does not differ from other types of plastic concrete. For example, it is not necessary to prolong the mixing time or convert/change existing weighing and transporter parts.

Especially during the warm seasons, bio ash may tend to be a little more "sticky" than traditional plastic concrete. This may require further resources etc. for washing and cleaning of production equipment and concrete mixing trucks in particular.

If a subsequent concrete mix has specific, aesthetic requirements, e.g. white concrete, it will be necessary to wash the truck and mixer thoroughly in order to avoid discoloration.

We have learned from the project that the same variation as to air content and consistency/slump can be expected from a commissioned and well-controlled production, whereas an increased spread as to the 28-day compressive strength can be expected.

Delivery, pouring and finishing

Due to the reddish colour the supplier should always inform his first-time customers about the colour of the concrete. It can be expected that some customers may refuse to receive bio ash concrete.

Due to the reddish colour side effect, bio ash concrete cannot normally be supplied for visible concrete constructions unless it has been agreed with the customer before each delivery.

In accordance with the rules of DS/EN 206-1 and DS 2626 supply must be limited to concrete in environmental class P (exposure classes X0 and XC1) via DS 2426.

It is not necessary to make special precautions concerning casting and protection against drying out compared to similar concrete with pozzolanic additions.

The colour of any new concrete mix should always be checked and inspected before production and supply.

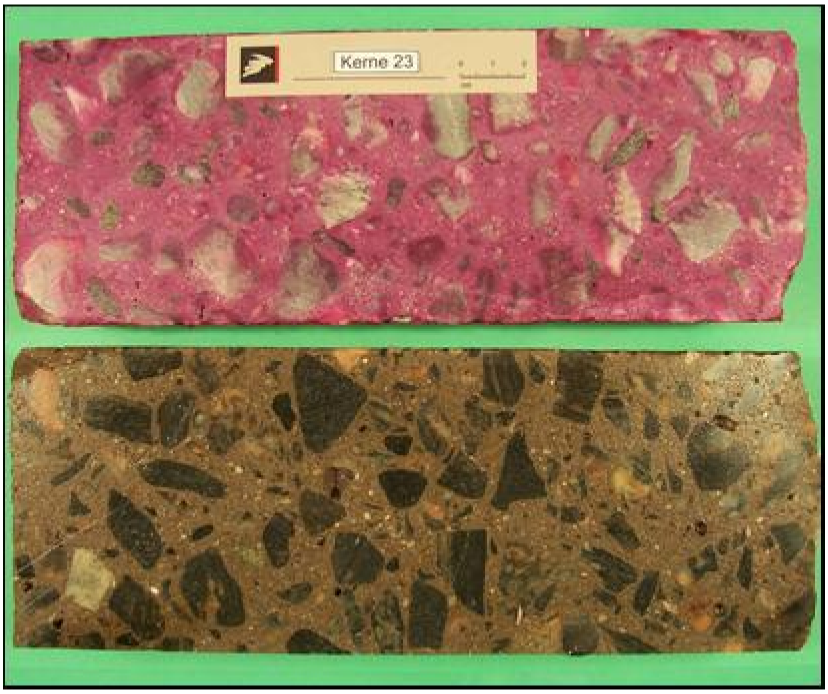
Durability

Collecting data from existing bio ash concrete constructions

As part of the project ”green concrete” a bridge in Jutland was constructed with bio ash concrete in 2002 (called Demo bridge). The bio ash concrete was proportioned to comply with the requirement for aggressive environmental class (exposure classes XD1, XS2, XF3 and XA2), and contained CEM I and bio ash. Furthermore concrete used as “fill in” at a waterbassin was investigated. This concrete was proportioned to comply with the demands to exposure classes X0 and XC1. From investigations conducted in 2007 the following can be concluded:

<u>Demo bridge</u>
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.

The chloride penetration into the bio ash concrete is higher the 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. It is therefore assessed that the relatively high chloride penetration is not due to the use of bio ash in concrete.



Surface of the concrete to the left. In the top image pH-indicator is sprayed onto the concrete to reveal carbonation. – no carbonation found.

Water basin / stormwater detention tank

The bio ash concrete around the water basin / stormwater detention tank 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.

Comparison between bio ash concrete and conventional concrete

This 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.

Laboratory tests

Using ash from both waste water treatment plants, concrete has been cast and tested regarding freeze/thaw, shrinkage and heat development. The coarse ash was milled to a finer particle size distribution.

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. The same has been observed at the tests of the setting time of the bio ash (paste).

Overall the concrete mixes with and with out bio ash had similar properties regarding durability and strength development, with the only major difference being the later setting time indicated in the heat development test.

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.

The results of the leaching tests show that 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.

The 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 (As, Cd, Cu, Mn, Ni, Pb, Zn) 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.

Material safety data sheet (MSDS) for bio ash

According to the law in Denmark the supplier has to describe the characteristics of his product with respect to safety in a document, which can be handed over to the consumer. AWS has prepared a MSDS in Danish for the bio ash. This can be seen at the projects homepage www.biocrete.dk

An important parameter in the MSDS is the content of breathable α-quartz. The content is less than 2 % indicating that there is no harmful impact on the working environment. The ash must be handled and stored in such a way that working operations causing dust emissions are avoided. The dry ash must be handled in closed systems to avoid inhalation of dust and stored in closed containers / silos.

Bioash concrete- in brief

The main experiences from the project can be outlined in the following way:

- Optimum mix design for the used ashes was achieved when 50 % of the coal fly ash was substituted with bio ash. (The design of the mixes was following the principles for mix design of ordinary concrete in Denmark.)
- Cements with different composition and properties have been used for production of bio ash concrete without problems.
- Different types of aggregate were used for production of bio ash concrete, sea dredged round aggregate, crushed granite and gravel from inland pits without problems.
- The admixtures used for production were the normal used ones i.e. lignosulphonates and vinsol resin products.
- The water requirement is higher for concrete with bio ash than for concrete without.
- Bio ash has an influence on the air content of the fresh concrete. The amount of air-entraining agent should be adjusted in preliminary tests.
- The colour of the concrete with bio ash was reddish and completely different from normal grey concrete. If this is a problem, the colour ca be reduced or even eliminated by not using more than 20 – 40 kg/m^3 for light bio ash and 5 – 10 kg/m^3 for red bio ash.
- Inspections of existing structures and laboratory tests indicate that concrete with bio ash has the same durability of comparable "normal" concrete.
- The leaching of heavy metals from bio ash concrete was at the same level as from ordinary concrete.
- The work environment was not affected by using bio ash in concrete compared to ordinary concrete.