Project BioCrete **Task ID: 8**

Final report

Production of bio ash concrete

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Content

1. Preface

“Bio Crete” is the acronym for a LIFE supported project”Utilisation of ash from incineration of wastewater sludge (bio ash) in concrete production”. The project activities have been defined in 10 tasks, and the present report is the final report of task 8, summarising purpose, task progress, results and experiences.

The project period is June 2005 to December 2007, and the project includes 4 participants: Avedøre Wastewater Services (AWS) as beneficiary, Lynettefaellesskabet (LYNIS) and Unicon Ltd. (UNICON) as partners and Danish Technological Institute (DTI) as consultant.

Ash from incineration of wastewater sludge (bio ash) has not previously been used in concrete on a regular basis. In order for bio ash to be an accepted raw material for concrete production it must be documented that concrete containing bio ash does not affect fresh and hardened concrete properties in a negative way neither on a short nor on a long term.

This report deals with production aspects and with conformity criteria for fresh and hardened concrete properties.

2. Existing production data on bio ash concrete.

2.1 DS/EN 206-1, Concrete – Part 1: Specification, performance, production and conformity

The new European standard for concrete, DS/EN 206-1:2002, was implemented in Denmark via DS 2426. With background in former project ”Grøn Beton”, DS 2426 legalised using bio ash from incineration of sludge from Danish WWTP’s and in limited and few specific concrete types. Bio ash was defined as a “*type II addition*”.

Use of concrete with bio ash was restricted to constructions in Passive Environmental Class according to DS 411 (corresponding to exposure classes XO and XC1 in DS/EN 206-1).

Passive Environmental Class is defined as dry environment without risk of corrosion and includes typical the following building constructions:

- *Constructions in indoor dry environment*
- *Some underground/soil covered foundations*

2.2 Unicons use of bio ash

Unicon A/S has been using bio ash for production of concrete in the Copenhagen area since the beginning of 2003. From 2003 bio ash was used at plant-Hedehusene, and further at plant-Avedøre Holme (2005), plant-Ejby (2006) and plant-Herfølge (2007).

Production of concrete with bio ash is only possible under the condition that supplementary/new silo facilities, weighing systems 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 red coloured side effect 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.

During this period Unicon has produced approx. 40.000 m^3 bio ash concrete mainly of the classes P08 and P12 using approx. 2.200 t of AWS bio ash. The typical/ average use of bio ash thus was approx. 50 kg per m^3 of bio ash concrete – including period I with a relative constant level between 30 and 40 kg/m^3 and period II with a higher and more variable level.

A milestone of 400.000 m^3 bio ash concrete was not obtainable, because the LYNIS bio ash was/is too lumpy to be used, and because the current (concrete)demand was lower than expected.

Unicon production and consumption of bio ash							
		2003	**2004**	**2005**	**2006**	**2007**	**Total**
Concrete volume	m^3/year	2.916	6.674	4.621	13.117	12.052	39.380
Bio ash consumption	t/year	85	221	182	1.062	721	2.271
Bio ash average conc.	kg/m^3	29	33	39	81	60	58

Figure 1. Production of bio ash concrete at UNICON plants using bio ash from AWS.

Further expansion of bio ash consumption is restricted due to:

- Restrictions in DS/EN 206-1 and DS 2426 concerning concrete types in more severe exposure classes
- Actual demand for the concrete types in question
- Side effect reddish colour due to red bio ash from AWS
- Lack of silo facilities on other Unicons plants near by Copenhagen

In this report, the production data from the plant in Hedehusene is compared with data for a similar concrete type (i.e. same strength class) produced without bio ash. Similar experience was recorded at the three other plants, but production and number of samples are lower at the three other plants.

The bio ash is only used in concrete to be placed in passive environmental class, strength classes 8 and 12 MPa. In addition to this - and outside this project - bio ash is used for full production for mixes not delivered according to DS/EN 206 standard (i.e. concrete with a compressive strength < 8 MPa as blinding layers etc.).

Data includes more that 10.000 m^3 concrete and more that 200 full sets of test results from bio ash concrete and from reference concrete without bio ash.

For every 100 m^3 the following properties were tested:

- Fresh concrete properties: slump, air content, density
- Hardened concrete properties: compressive strength, the increase in strength and the standard deviation on the strength results

The European Standard for production of concrete EN 206 was made obligatory during the project period. The demands for the test specimens and thereby specifications for moulds/test equipment in EN 206 were more strict than in the present Danish Standard. It was therefore necessary to invest in new moulds (casting forms) for testing of compressive strength.

2.3 Results, concrete properties

Results from type P12 where production and number of test samples are highest are presented in Figure 3.

As mentioned in previous section dosage level was split in to two periods. Figure 2 shows which dosages were tested during the two periods.

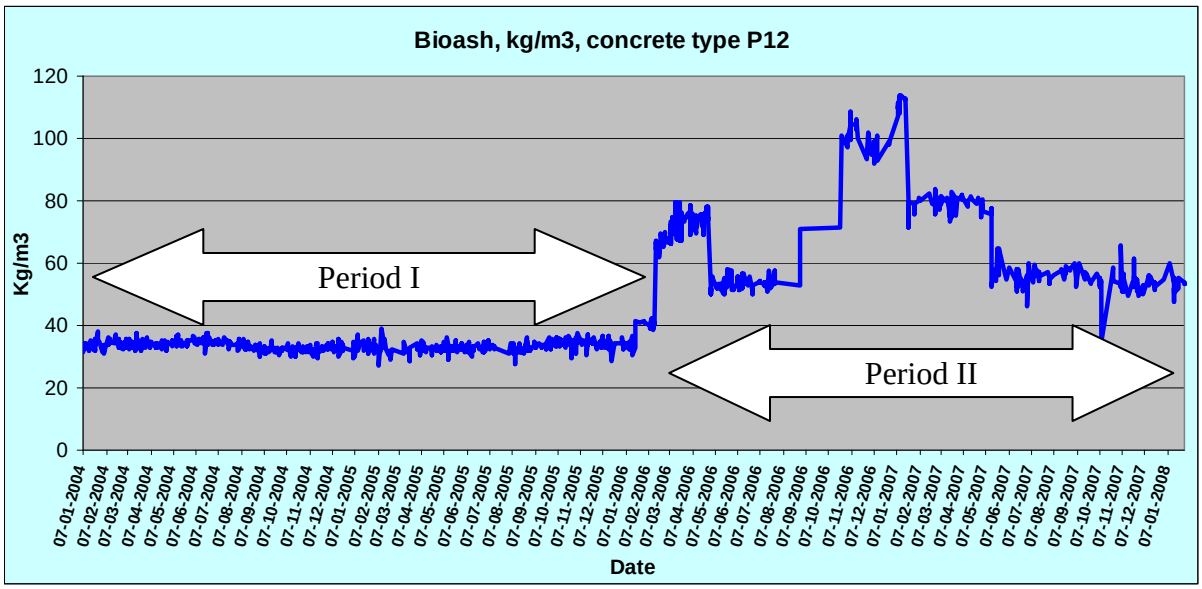

Figure 2. Content of AWS bio ash in concrete type P12 bio ash concrete from production plant Hedehusene, 2004-2007.

In general mixing properties and quality of bio ash concrete has been acceptable, and there were no problems conforming to the criteria's in DS/EN 206-1 for slump/consistency, air content, density and compressive strength. No bleeding was measured or seen.

Mix design, test results and variation/STD in concrete properties appears in the following table.

			P12 with bio ash				P12 ref. concrete	
	Parameter	**Unit**	**Period I**		**Period II**		**Period I + II**	
			AVG	**STD**	**AVG**	**STD**	**AVG**	**STD**
Mix design ("average" recipe in period)								
	Cement(C)	kg/m^3	**152**		**151**		**142**	
	Fly ash	kg/m^3	**76**		**75**		**94**	
	Bio ash	kg/m^3	**33**		**66**		**0**	
	Water(W)	kg/m^3	**169**		**166**		**149**	
	Extra super plasticizer	kg/m^3	**0,5**		**1**		**0**	
	W/C eq (k = 0.5 for ash)	kg/kg	**0,82**		**0,75**		**0,83**	
	Production	m^3	**5075**		**2508**		**9363**	
Measurements								
	Slump (workability)	mm	**132**	**28**	**141**	**28**	**139**	**34**
	Compr. Strength (CS) 7d	MPa	**9,6**	**2,4**	**9,5**	**2,3**	**10,2**	**2,2**
	Compr. Strength 28d	MPa	**17,6**	**4,1**	**17,4**	**4,5**	**18,6**	**3,8**
	(CS 28d)/(CS 7d)		**1,8**		**1,8**		**1,8**	
	Air	% vol.	**4,5**	**1,5**	**4,2**	**1,5**	**3,7**	**1,2**

			P12 with bio ash				P12 ref. concrete	
	Parameter	**Unit**	**Period I**		**Period II**		**Period I + II**	
			AVG	**STD**	**AVG**	**STD**	**AVG**	**STD**
Mix design ("average" recipe in period)								
	Density	kg/m^3	**2244**	**40**	**2242**	**44**	**2258**	**33**
	Number of test results		**106**		**57**		**175**	

Figure 3. Test results and mix design at plant Hedehusene, full scale production

2.4 Conclusions and experience from production and testing

- Best or optimal mix design is 50 % bio ash, 50 % fly ash (by weight), and a total max sum of fly + bio ash at app. 100 – 125 kg/m^3 concrete.
- Fresh and hardened properties fulfil specifications in DS/EN 206-1 and DS 2426 for in environmental class Passive (P) without problems
- Concrete with bio ash does not deviate from concrete without bio ash with respect to 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) or/and, more preferable, added super plasticizer to compensate for higher water need
- Bio ash contributes to strength, but in minor scale than fly ash.
- Slightly higher variation in concrete strength, but no significant variation in fresh and hardened concrete properties.
- "Earth moist concrete" (or no slump concrete) should not be 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.
- Bio ash increases the water need of the concrete / lowers the consistency (slump)
- The higher absolute dosage the lower the relative "use" of the bio ash as a contributor to compressive strength. At a given point the mix will be "saturated".
- See also figure 3.

3. Pre-testing of bio ash concrete for Environmental classes M, A and E

3.1 Design of mixes and results

As mentioned in section 2.1 DS/EN 206-1 and DS 2524 does not permit using bio ash in Moderate (30 MPa, moist and frost), Aggressive (35 MPa, water saturated and frost etc.) and in Extra Aggressive environmental class. Thus, one objective of Task 8 is to establish a suite of EN-standard pre-tested higher class bio ash concrete mixtures in order to create a background for an extension of the concrete classes where bio ash can be used as an ingredient. Also concrete in Passive Environmental class and Strength class 20 MPa was pre-tested, which is higher than the concrete types described in section 2.

The mix designs and the quality measurements are shown in figure 4. For these 4 classes the pre-testing results are satisfactory. Thus, the mixing properties and the quality of bio ash concrete are acceptable, and there are no problems conforming to the criteria's in DS/EN 206-1 for slump/consistency, air content, density, compressive strength and frost resistance. No bleeding was measured or seen.

	Parameter	Unit	Exposure and strength class			
			P20	M30	A35	E40
Mix design (recipe)						
	Cement(C)	kg/m^3	215	299	391	368
	Fly ash	kg/m^3	22	45	39	37
	Bio ash	kg/m^3	22	45	39	37
	Micro silica fume	kg/m^3	0	0	0	5
	Water(W)	kg/m^3	166	178	179	157
	Plasticizers	kg/m^3	2,5	3,1	3,9	3,7
	Air (target)	% vol.	5,1	4,0	4,2	7,5
	W/C eq (k = 0.5 for ash)	kg/kg	0,67	0,52	0,42	0,36
Measurements						
	Slump (workability)	mm	160	140	170	120
	Compr. Strength(CS) 7d	MPa	15,4	35,7	42,1	28,1
	Compr. Strength 28d	MPa	25,8	51,1	57,6	48,0
	(CS 28d)/(CS 7d)		1,68	1,43	1,37	1,71
	Air, fresh concrete	% vol.	5,1	4,0	4,2	7,5
	Air, hardened concrete	% vol.	-	-	3,8	9,3
	Spacing factor	mm^{-1}	-	-	0,16	0,08
	Frost resistance, air void structure		-	-	ok	Ok

Figure 4. Test results and mix design for concrete types in more exposed environmental classes than accepted in DS/EN 206-1 and DS 2426 for bio ash concrete.

4. Side effect – reddish coloured concrete / red bio ash

4.1 Concrete with light bio ash (from Damhusåen WWTP)

With background in the undesirable side effect on reddish concrete colour when using the red bio ash from AWS, a test series was done with light bio ash produced at Damhusåen WWTP, cf. Task 3.

The results were:

- Light Bio ash does on the whole only influence concrete colour of the fresh and hardened marginally.
- Light Bio ash and Reddish Bio ash has same technical impact/effect on fresh and hardened concrete.

The detailed test results were.

	Parameter	Unit	Exposure and strength class			
			P12		P/A35	
			Red bio ash	Light bio ash	Fly ash	Light bio ash
Mix design (recipe)						
	Cement(C)	kg/m^3	140	140	346	370
	Fly ash	kg/m^3	50	50	17	0
	Bio ash	kg/m^3	50	50	0	17
	Water(W)	kg/m^3	154	154	149	156
	Plasticizers	kg/m^3	1,5	1,5	1,1	1,0
	W/C eq (k = 0.5 for ash)	kg/kg	0,73	0,74	0,39	0,40
Measurements						
	Slump (workability)	mm		130		110
	Compr. Strength(CS) 7d	MPa	9,3	11,9	34,5	34,5
	Compr. Strength 28d	MPa	17,4	22,2	44,5	46,4
	(CS 28d)/(CS 7d)		1,87	1,87	1,28	1,34
	Air, fresh concrete	% vol.	4,3%	4,0 %	7,3 %	7,4 %
	Air, hardened concrete	% vol.	-	-	-	7,7
	Spacing factor	mm^{-1}	-	-	-	0,21
	Frost resistance, air void structure					ok

Figure 5. Data for red bio ash and light bio ash concrete.

4.2 Concrete with red bio ash

With background in the undesirable side effect on the concrete colour when using the reddish Bio ash from Avedøre Wastewater Services e test series was done with variable dosage of reddish Bio ash going from 15 kg/m^3 to 53 kg/m^3. The tests included two concrete types – respectively 20 MPa (medium cement content) and 35 MPa (high cement content).

The detailed test results were:

- In concrete type 20 MPa even 15 kg of bio ash (7 % of cement weight) affects the colour of the concrete.
- In concrete type 35 MPa even 24kg of bio ash (7 % of cement weight) effects the colour of the concrete
- Increased dosage gives a more and more reddish colour
- After drying out for some days the reddish colour is still visible, but slightly decreased
- The effect on concrete colour for en given fixed mass of bio ash decreases with increased mass of cement
- As a supplementary result the figures for strength (corrected for measured air content) indicates that the actual bio ash in question which in itself possesses no cementations properties but in the presence of water and cement at ordinary temperatures can form cementations properties. A part of the contribution to strength development is however assumed to come from the “filler effect”.

Parameter	Unit	Exposure and strength class							
		P20				P35			
		Ref.	A	B	C	Ref.	A	B	C
Mix design (recipe)									
Cement(C)	kg/m^3	225	216	212	205	340	327	324	320
Fly ash	kg/m^3	68	50	34	17	68	42	30	10
Bio ash	kg/m^3	0	15	35	46	0	24	38	53
Water(W)	kg/m^3	161	159	156	150	153	149	148	145
W/C eq (k = 0.5 for ash)	kg/kg	0,62	0,64	0,63	0,64	0,41	0,41	0,41	0,41
Measurements									
Slump (workability)	mm	150	120	90	100	120	160	110	100
Compr. Strength(CS) 7d	MPa	20,1	18,7	16,9	13,2	28,9	27,7	27,2	25,5
Compr. Strength 28d	MPa	33,2	29,5	28,3	21,5	38,5	36	36,5	32,9
(CS 28d)/(CS 7d)		1,7	1,6	1,7	1,6	1,3	1,3	1,3	1,3
Air, fresh concrete	% vol.	3,3	7,0	7,9	11,0	5,8	8,4	9,2	11,0
Density	kg/m^3	2293	2203	2157	2095	2296	2223	2225	2155

Figure 6. Data for concrete slabs with different content of red bio ash (se figure 7)

The results were (se photos below):

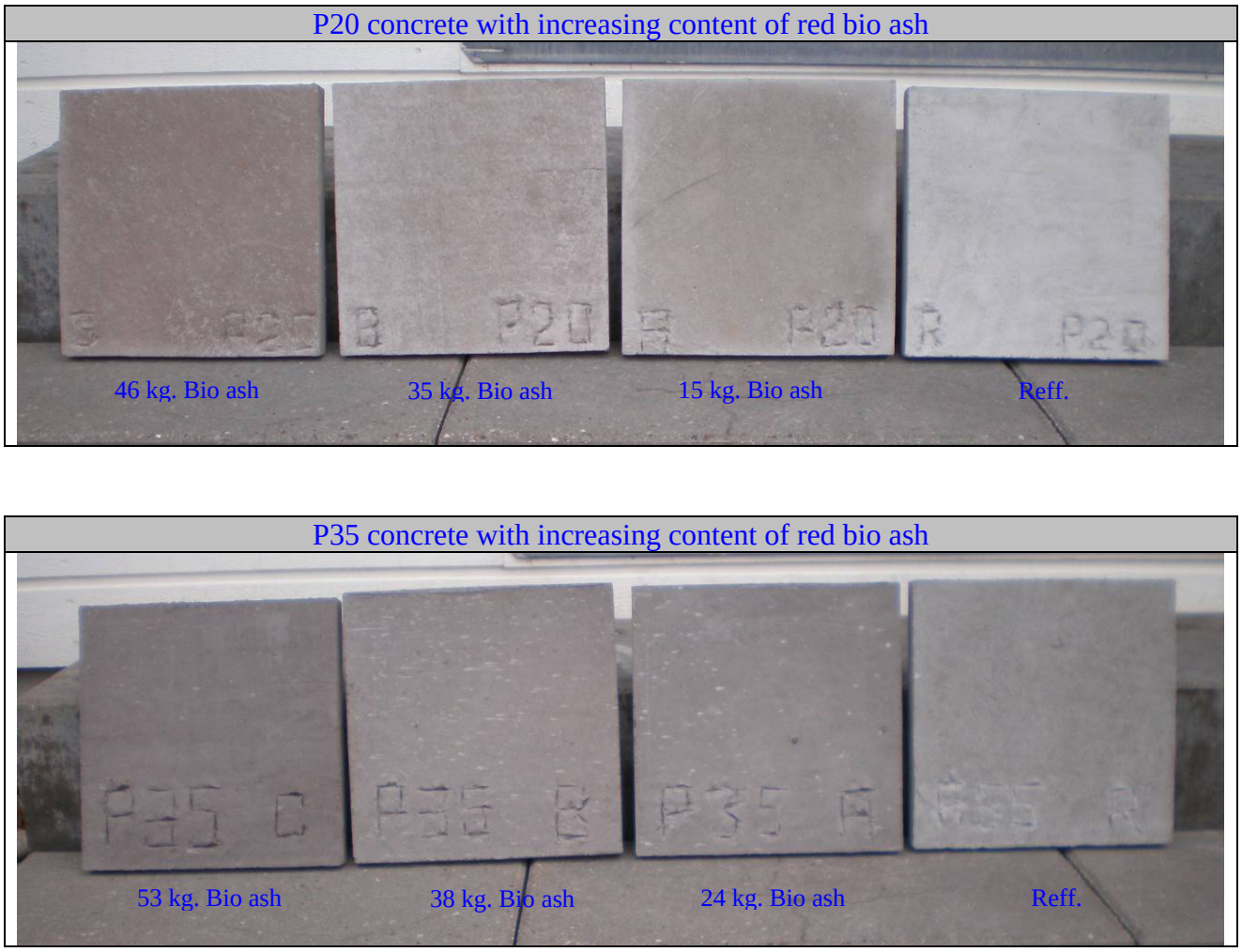

Figure 7. Variable content of bio ash for concrete P20 with low cement content and concrete P35 with high content of bio ash.

5. Conclusion

The overall conclusion concerning production and concrete properties are:

- The overall conclusion is that bio ash from AWS, i.e. the ash from a fluidized bed incinerator, can be used for concrete production for many purposes, and in a European perspective it will possible to use bio ash concrete as an important part of the total amount of concrete produced.
- Bio ash increases the water need of the fresh concrete which means that extra water and cement/plasticizer musty be added to maintain workability
- Bio ash can substitute fly ash – substitution factor from fly ash to Bio ash is 1 to 2 by weight
- Not more that 50 % of the fly ash should be substituted with Bio ash and total sum of fly ash + bio ash should not be higher that 100 – 125 kg/m^3.
- It is possible to fulfil DS/EN 206-1 specifications for both Passive, Moderate, Aggressive and Extra Aggressive Environmental Class and thereby covering all exposure classes
- Technically Light Bio ash does not differ clearly from red bio ash apart from the colour
- Transport in closed tank truck, storage in standard fly ash -silo is not a problem.
- Weighing and mixing is not a problem.
- Concrete with Bio ash is a little more sticky for which reason it, especially in the summertime, can be more difficult to clean mixer and truck
- Bio ash is not suitable in earth moist concrete with open structure and very low water content, / resulting lake of strength will occur
- Reddish Bio ash affects immediately the colour of the concrete from so low a dosage as 5-10 kg/m^3. Thus, for visible structures the maximum use of bio ash will often be limited by the possible colour problem, and not by the technical quality of the concrete.
- Higher concrete strength = cement content, reducers the colour effect from reddish Bio ash