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Danish Centre for Green Concrete

By

Jesper Sand Damtoft*, Mette Glavind and Christian Munch-Petersen*****

ABSTRACT

Cement and concrete have an important role to play in enabling Denmark to fulfil its obligation to reduce the CO_2 emission by 21% of the 1990 level before 2012 as agreed to at the Kyoto conference. It is also possible to use residual products – thus reducing the need to landfill these materials – while still maintaining a high concrete quality.

This is the background for the Danish centre, a co-operative venture involving all sectors related to the use and production of concrete. The goal of the centre is to reduce the environmental impacts of concrete through the development of new resource-saving binder systems and increased recycling and energy recovery of waste materials.

Keywords: Binder, bridge, cement, fly ash, green concrete, CO_2 emissions, energy, recycling, residual products.

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* Executive Manager, Research Development and Testing, Aalborg Portland A/S, Denmark
**Project Manager, Danish Technological Institute, Concrete Centre, Denmark
*** Centre Manager, Danish Technological Institute, Concrete Centre, Denmark

BACKGROUND TO THE ESTABLISHMENT OF THE DANISH CENTRE FOR GREEN CONCRETE

By volume alone, concrete is the world's most important construction material. Concrete is an artificial rock composed of aggregates, water and cement. The raw materials are readily available. By reinforcing the concrete with steel, a uniquely strong and durable material is obtained which in terms of shape and size can be designed almost at will by architects and civil engineers. Annually, approximately 5 km^3 is used for construction world-wide. In Denmark alone, 8,000,000 t of concrete is produced annually. This corresponds to 1.5 t of concrete per capita annually.

Concrete is an environmentally friendly material and the overall impact on the environment per ton of concrete is limited (1). The CO_2 emission related to concrete production, i.e. primarily from cement production, is between 0.1 and 0.2 t per tonne of produced concrete. However, the absolute figures for the environmental impact are quite significant, due to the large amounts of cement and concrete produced. From cement and concrete production a total quantity of CO_2 of 800,000-1,600,000 t per year is emitted. This corresponds to approximately 2 % of Denmark's total CO_2 emission.

The solution to this environmental problem is not to replace concrete with other materials but to reduce the environmental impact of concrete and cement. Again, even a small reduction of the environmental impact per tonne of concrete will result in large environmental benefits because of the vast amount of concrete produced today.

The potential environmental benefit to society of being able to build with green concrete is huge. It is realistic to assume that technology can be developed which can halve the CO_2 emission related to concrete production. With the large consumption of concrete this will potentially reduce Denmark's CO_2 emission by as much as 1 %.

Concrete can also be the solution to environmental problems other than those related to CO_2 emission. It may be possible to use residual products from other industries in the concrete production while still maintaining a high concrete quality. During the last few decades, society has become aware of the problems associated with landfilling of residual products, and limits, restrictions and taxes have been imposed. As several residual products have properties suited for concrete production, there is a large potential to increase material recycling by investigating the possible use of these for concrete production.

When assessing the environmental compatibility of concrete it is essential to consider all life cycle phases – and not only the environmental impacts associated with the production and use of the material itself. In Northern Europe only a very minor part of the environmental impact associated with buildings and structures originates from the production and use of the building materials themselves. It has been calculated (3) that the energy consumption needed to produce a reinforced concrete office or residential building is 500 MJ per m^3 space. Over a 50-year lifespan, however, 15,000 MJ per m^3 space will be used for heating and electricity consumption. In other words, only 3% of the total energy consumed during the life of the building come from the concrete and other building materials used in its construction.

This study points to durability and insulation as key parameters to be considered if real environmental improvements are to be achieved.

Even taking these considerations into account, it is still important to reduce the environmental impact of the materials themselves, not least, because environmental improvement is a competitive parameter. Building materials with reduced environmental impact are often less expensive to produce. Furthermore, environmental performance is increasingly taken into account in tenders. The material with the best environmental parameters is the most likely to be used.

Life cycle inventories of concrete-based products show that the concrete mixture proportions have a major influence on the total life cycle impact (2). Combined with reducing the environmental impact of the constituent materials, improved mixture design may result in concrete with significantly improved performance.

CENTRE FOR GREEN CONCRETE – A UNITED BUSINESS EFFORT

The environment has been a serious issue in the Danish concrete industry for several years. Matters addressed include environmental studies, environmental management, environmentally correct design and life cycle inventories, (4, 5, 6). Concrete with reduced environmental impact, the so-called green concrete, has been produced in Denmark for some years, (7). However, the challenge is to develop a new technology for that type of concrete and this is the background for the Danish Centre for Green Concrete.

The technology must consider all phases of a concrete structure's life cycle and it must include all aspects of performance, i.e.

- mechanical properties (strength, shrinkage, creep, static behaviour etc.)
- fire resistance (spalling, heat transfer etc.)
- workmanship (workabililty, strength development, curing etc.)
- durability (corrosion protection, frost, new deterioration mechanisms etc.)
- thermodynamic properties
- environmental aspects (CO_2-emission, energy, recycling etc.)

The Danish Centre for Green Concrete was established on July 1, 1998 with the aim of creating a united business effort towards reducing the environmental impacts of concrete. Participants represent all stakeholders in the life cycle of concrete products:

- Institute: Danish Technological Institute, Concrete Centre
- Cement producer: Aalborg Portland A/S
- Aggregate producer: AB Sydsten
- Concrete producer: Unicon Beton A/S
- Contractor: Højgaard & Schultz a/s
- Consultant: COWI
- Building owner: The Danish Road Directorate
- Universities: The Department of Buildings and Energy, Technical University of Denmark and The Department of Building Design, Building Energy and Energy Planning, Aalborg University

The Ministry of Trade and Industry funds the centre through a so-called centre contract. The partners form a “centre without walls” with a formalised management structure and an agreed work programme, but with the work carried out by the partners at their own facilities. The centre has a budget of approximately DKK 22 million (approximately $ 2.8 million) – one of the largest Danish concrete development projects ever. The duration of the contract is 4 years.

The industrial partners and the Danish Road Directorate finance their own contribution. The contribution from the Danish Technological Institute is 25 % financed by the institute itself, whilst the Ministry of Trade and Industry supplies 75 % of the funding. The universities are 100 % financed by the Ministry of Trade and Industry. The Ministry of Trade and Industry supplies an amount equivalent to the industrial partner’s contribution.

The goal of the project is to reduce the environmental impact of concrete. This will be achieved through the development of new resource-saving binding systems and increased recycling of materials. New technology will be developed for all phases in the design, construction and use of concrete structures. This applies to structural design, specification, manufacturing and operation and maintenance.

The results will be implemented in a pilot project involving the dimensioning and construction of a road bridge made of various forms of green concrete. A Danish Road Directorate special concrete specification for resource-saving concrete structures will be prepared.

ENVIRONMENTAL AND TECHNICAL GOALS

The centre has defined a number of alternative environmental requirements with which green concrete structures must comply:

- CO_2 emissions shall be reduced by at least 30 %.
- At least 20 % of the concrete shall be residual products used as aggregate.
- Use of concrete industry’s own residual products.
- Use of new types of residual products, previously landfilled or disposed of in other ways.
- CO_2-neutral, waste-derived fuels shall replace at least 10% of the fossil fuels in cement production.

The goal for CO_2 emissions is in accordance with the Danish obligations in the Kyoto agreement (21 % reduction before 2012 compared to the 1990 level).

In addition to the environmental goals there are a number of environmental intentions. Most important are: to avoid the use of materials which contain substances on the Danish Environmental Protection Agency’s list of unwanted materials, not to reduce the recycling ability of green concrete compared with conventional concrete and not to increase the content of hazardous substances in the wastewater from concrete production compared with wastewater from production of existing concrete types.

The technical goals for the centre are to obtain the same technical properties for the green concretes compared to conventional concretes – or to determine in what way the properties differ. The compressive strength goals for the concretes are:

- Aggressive environmental class (outdoor, horizontal): 28-day strength > 35 MPa and 56-day strength > 85 % of the strength of a reference concrete.
- Passive environmental class (indoor): 28-day strength > 12 MPa and 56-day strength > 85 % of the strength of a reference concrete.

The compressive strength goals for the 28-day strength correspond to the minimum requirements in the Danish standard for concrete materials, DS 481. A reference concrete is defined as a conventional concrete produced in large amounts.

FOUR WAYS TO PRODUCE GREEN CONCRETE

Four ways to produce green concrete are being investigated, see Fig. 1:

1. To increase the use of conventional residual products, i.e. fly ash.
2. To use residual products from the concrete industry, i.e. stone dust (from crushing of aggregate) and concrete slurry (from washing of mixers and other equipment).
3. To use residual products from other industries not traditionally used in concrete, i.e. fly ash from biofuels and sewage sludge incineration ash (from sewage treatment plants).
4. To use new types of cement with reduced environmental impact.

Altogether 14 concrete types have been tested in a basic green concrete test programme for workability, changes in workability after 30 min., air-content, compressive strength development, E-modulus, heat development, homogeneity, water separation, setting time, density and pumpability. Frost testing, chloride penetration and an air void analysis have been carried out for the concretes in the aggressive environmental class. Furthermore, the water/cement ratio, water/binder ratio and the chloride content have been calculated from the mixing report of the precise mixture proportions and from the chloride content in the different raw materials

From the results of the basic green concrete test programme the most promising green concrete types have been selected and are currently exposed to more advanced testing for mechanical properties, fire resistance, workmanship, durability and thermodynamic properties. The concrete types selected are shown in Table 1 and Table 3 for concrete in passive and aggressive environmental class respectively. It can be seen that the four principles of producing green concrete are combined in order to achieve the most environmentally friendly concrete.

The reference concretes, that are representative of typical Danish concretes, contain both fly ash and silica fume. Both of these materials are residual products from another production, i.e. production of electricity and production of silicon or ferrosilicon, respectively. In short, Portland cement is used to obtain early strength, silica fume to give 28-day strength and fly ash to give pumpability. The reason for the relatively high cement content in concrete P6, P7, A5 and A6 is that they are typical Swedish concrete types. There is no tradition in Sweden for using fly ash.

In order to achieve a satisfactory workability, i.e. a slump of approximately 100 mm, it was necessary to add superplasticizer to most of the green concretes. This must be seen in relation to the reference concretes, that contain no superplasticizer.

When calculating the equivalent water-cement ratio an activity factor of 0.5 for fly ash and 2.0 for microsilica has been used. The activity factor for sewage sludge incineration ash and for fly ash from biofuels has been set to the same as for conventional fly ash, i.e. 0.5. This will have to be verified.

In Table 2 and Table 4 an evaluation of the environmental goals and intentions and the compressive strength goals is shown for the concretes from Table 1 and Table 3. All the concretes fulfil one or more of the environmental goals. For the concretes fulfilling the goal regarding reduction of the CO_2 emission compared to the reference concrete this reduction is for e.g. the concrete with 50 % and 40 % of fly ash in passive environmental class and aggressive environmental class respectively, higher than the 30 % reduction goal.

On the other hand, for other concrete types where the reduction in CO_2 emission is lower or at the same level as the goal reduced CO_2 emission must be obtained from activities in the other life cycle phases. This applies for i.e. concrete with 30 % fly ash from biofuels of powder and concrete with cement with reduced environmental impact, For concertos containing special fillers and sewage sludge incineration ash which contain higher amounts of Zn, V, Pb, Cu and P_2O_5 as compared to Portland cements and fly ash from coal combustion, one should be aware of the problems associated with an increased content of these substances in the wastewater from the concrete production plant. This will have to be investigated. However if the wastewater is being recycled – as it is at many concrete production plants – the problem may not exist. For concrete containing fly ash from biofuels, the increased chloride content compared to concrete containing conventional fly ash makes it necessary to investigate both the chloride content in the wastewater at the concrete production plant and the consequences of recyling the concrete. Avoiding the use of materials that contain substances mentioned in the list of unwanted materials prepared by the Danish Environmental Protection Agency has been fulfilled by substituting the superplasticizer normally used at the participating concrete plants with a superplasticizer without free formaldehyde.

In general, there are no problems in achieving the compressive strength goals. For the concrete types in the aggressive environmental class the 56-day compressive strengths are much higher than the reference strength, that means that the environmental impact can be further reduced while still maintaining the same strengths as for the reference concretes. The only exception is the concrete with concrete slurry in passive environmental class where the 56-day compressive strength is only 80 % of the compressive strength of the reference concrete. However, it is known from the basic green concrete test programme that the goal for the 56-day compressive strength can be achieved.

Preliminary results from investigation of mechanical properties of a green concrete show that these do not differ significantly from the mechanical properties of the reference concretes. Preliminary results from investigation of workmanship show that some of the green concretes may lose workability more quickly than the reference concretes, be more adhesive or require a longer resting time before finishing can begin. It is expected that some of these problems can be solved by optimizing the type and amount of chemical admixtures.

With regard to durability preliminary results indicate that the green concrete A1 with a high amount of fly ash has problems with obtaining a satisfactory frost resistance. Furthermore, increased carbonation is observed in relation to the reference concrete. On the other hand the chloride resistance is good. The green concrete A3 with sewage sludge incineration ash has also limited frost resistance but also good resistance to chloride penetration. Results for the green concretes A5 with concrete slurry and A6 with stone dust indicate slightly reduced resistance to chloride penetration. This may not be due to the addition of the concrete slurry and stone dust but could be because the concrete type (Swedish) that A5 and A6 represents, i.e. high cement content and no fly ash and silica fume, in general, has a lower resistance to chloride penetration than a concrete with pozzolans such as the Danish reference concrete.

In the following pages the activities related to development of cement with reduced environmental impact and the use of sewage sludge incineration ash are further elaborated.

CEMENT WITH REDUCED ENVIRONMENTAL IMPACT

So-called “mineralised” cement is being tested in one of the centre projects. The cement is based on an intermediate product, clinker, which is produced with minor additions of mineralisers ($CaSO_4$ and CaF_2) to the kiln resulting in a 5% reduction in energy consumption and a 5-10% increase in 28-day strength of the cement. The higher strength enables the cement content to be reduced, resulting in a further total energy reduction per m^3 concrete without compromising concrete strength and durability (8).

Further reductions in the clinker content in concrete have been achieved by the successful introduction of a high-strength limestone cement based on mineralised clinker. The filler content of this cement is 14%. The new Portland limestone cement has significantly higher early as well as late strengths (EN 196 mortar 1 and 28-day strengths of 27 and 66 MPa respectively). This enables it to be used in applications such as in the precast industry, where high early strengths are a requirement, without having to increase the cement content. That this has proved possible is due to the synergetic effect of combining clinker mineralised by CaF_2 and SO_3 with finely divided limestone filler, that results in much higher strengths than would normally be expected (9), (10).

Aalborg Portland aims to substitute at least 1/3 of the fossil fuel with CO_2 neutral alternative fuels in its largest kiln. This will be achieved by processing combustible waste into an alternative fuel, which can be used in cement production (11). When the developments now in progress are completed, the CO_2 emission from combustion of fuel in cement production is expected to be reduced to less than 2/3 of its original level (Fig.2)

CONCRETE WITH SEWAGE SLUDGE INCINERATION ASH

The production of fly ash is being significantly reduced in Denmark. The reason for this is the Danish Government's CO_2 reduction policy, that aims to gradually phase out coal-fired electricity production. An important task for the Centre for Green Concrete has been to investigate possible fly ash replacements, readily available in Denmark.

The most promising material is sewage sludge incineration ash (SSIA). The SSIA is a residual product from sewage treatment plants. In Denmark the annual production of SSIA 10-15.000 tons is disposed of in landfills. The quality of SSIA can vary, depending on the part of the country from which it originates. If produced in industrialised areas, SSIA may contain increased levels of heavy metals or harmful organic substances. In terms of overall chemical composition, SSIA differs from normal fly ash in having a higher CaO content and lower SiO_2 and Al_2O_3 contents, (table 5).

Addition of different amounts of SSIA added as a substitute for ordinary fly ash from coal combustion has been tested in concrete designed for passive and aggressive environmental classes.

The SSIA concretes meet the Centre's environmental criteria of introducing new types of residual products previously landfilled or disposed of in other ways For the concrete in aggressive environmental class the environmental criteria of using waste-derived fuels for cement production is also fulfilled, (Tables 2 and 4). Compressive strengths are shown in Fig. 3 for reference concrete and concrete produced from SSIA. The difference between the various types of concretes with and without SSIA is that the contents of 17 and 10 % fly ash in the passive and aggressive environmental classes respectively, are replaced by SSIA.

It can be seen that the strengths of the concretes with SSIA are at the same level as the reference concretes. The goals of at least 12 MPa at 28 days, and a 56-day strength greater than 85 % of that of the reference concretes are achieved.

It was previously mentioned that the frost resistance of the concrete with SSIA is not satisfactory. Frost testing using salt water has been carried out according to a revised version of the Swedish standard SS 13 72 44. set of four test specimens were tested approximately 28 days after casting and a set of four test specimens were tested approximately 56 days after casting. Furthermore, a set of four test specimens were cut and exposed to carbonation 28 days after casting and tested 56 days after casting. The results are shown in Table 6,).

The requirements in the Danish concrete standard DS 481 are as follows:

- scaling after 56 days shall be less than 0.2 kg/m^3

or

- scaling after 56 days shall be less than 0.5 kg/m^3 and not more than twice the scaling at 28 days.

Thus, the requirements are met for the cases where the age of the test specimens at the start of testing was 31 days and 59 days after casting, even though the scaling of the 59-

day specimens is significantly higher than the 31-day old specimens. The test specimens exposed to carbonation before the start of the testing do not fulfil the requirements.

The reason for the problems with frost resistance might be a relatively coarse air void structure. The spacing factor measured at 0.3 mm does not fulfil the requirement of 0.20 mm that is set in DS 481. Thus, an optimisation of the air void structure might solve the problem as regards to frost resistance.

Testing for the penetration of chloride ions into concrete was carried out according to the so-called CTH-method developed by Tang Luiping, (12). After 28 days the chloride diffusion coefficient was measured to $4{,}6 \times 10^{-12}$ m^2/s and after 85 days to $3{,}7 \times 10^{-12}$ m^2/s. According to the CTH-method the concrete with SSIA had good resistance to the penetrations of chloride ions into concrete (good is defined as a chloride diffusion coefficient less than 8×10^{-12} m^2/s). For the concrete with SSIA in the passive environmental class a special problem related to workmanship was observed, i.e. a long resting time before finishing can begin. However, as stated previously this might be solved with an optimisation of the type and amount of the chemical admixtures.

The above mentioned problems as well as other properties related to fire and mechanical properties are currently being investigated further in a comprehensive testing programme. On the basis of the results available, SSIA is being evaluated as a possible pozzolanic constituent in future concrete production.

STRUCTURAL SOLUTIONS AND OPERATION AND MAINTENANCE

Other development projects in the Centre concern the operation and maintenance of green concrete structures, green structural solutions and structural solutions for green concrete.

A case study will be used to compare the environmental impact of building a typical Danish motorway bridge by conventional means, with that of building a "green" bridge using the best environmental practice in its construction. The structural bridge components which have been preliminarily selected for this case study are given in Table 7. The service lives of the "green" concretes given in Table 6 are first estimates, that will have to be verified during the project.

It appears that aspects other than the environmental impact from the green concrete or the conventional concrete itself will have an influence on the concrete structure's environmental impact, e.g. the supplementary protection and the service life. Considering the column it might be more “green” to use a Compact Reinforced Concrete (CRC, an ultra-high strength fibre-reinforced concrete (13,14)) compared to a green concrete with no supplementary protection, because the expected service life is longer - even though the environmental impacts related to the production of the CRC are much higher than the environmental impacts related to the production of the green concrete.

Furthermore, the impact of the maintenance and repair activities will have an influence. Based on the outcome of the durability testing, suitable maintenance and repair methods will be elaborated for environment-friendly concrete structures.

A life-cycle screening will be carried out in order to determine the environmental impact of the concrete structure and to determine whether it fulfils the environmental goals of the Centre.

CONCLUSIONS

The results obtained by the Danish Centre for Green Concrete point to ways of significantly reducing the environmental impact of concrete by using "greener" cements, by optimising the use of residual products as concrete additions and by optimising the operation and maintenance methods. The results so far indicate that the environmental targets set up for the Centre will be achieved.

The potential environmental benefit to society of being able to build with green concrete is substantial. It is realistic to assume that technology can be developed that can halve the CO_2 emission related to the use of concrete structures which with the large volumes of concrete consumed will mean a potential reduction of Denmark's total CO_2 emission by as much as 1 %.

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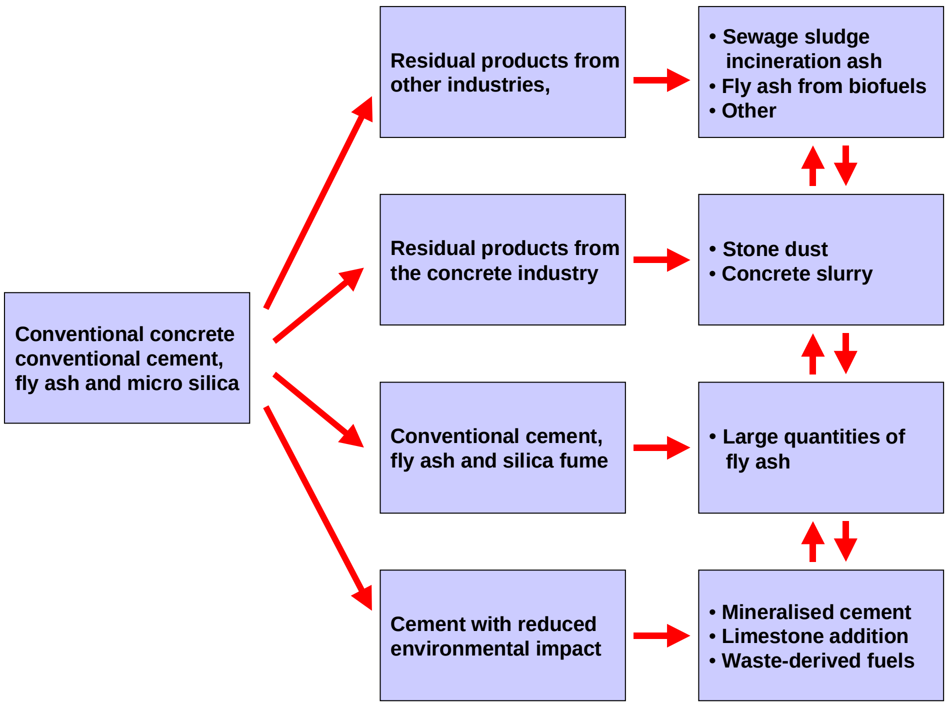

Fig. 1. Overview – concrete developments in the Centre for Green Concrete. New types of cement and binders can be utilised in combination with the residual products.

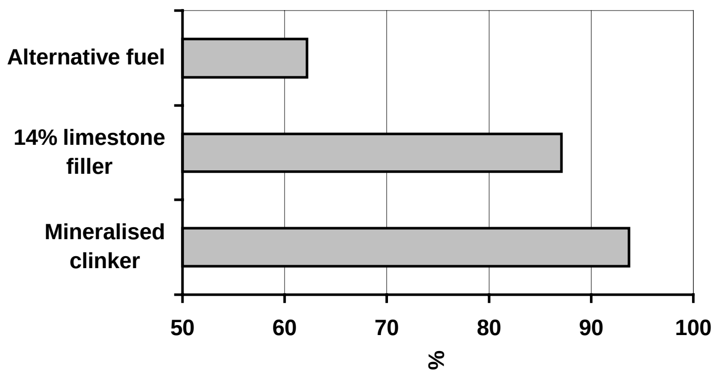

Fig. 2. CO_2 reductions (excl. calcination) expected after present research and development is fully implemented in Aalborg Portland's cement production. 100% = CO_2 emission from Aalborg Portland's largest cements kiln during conventional cement production.

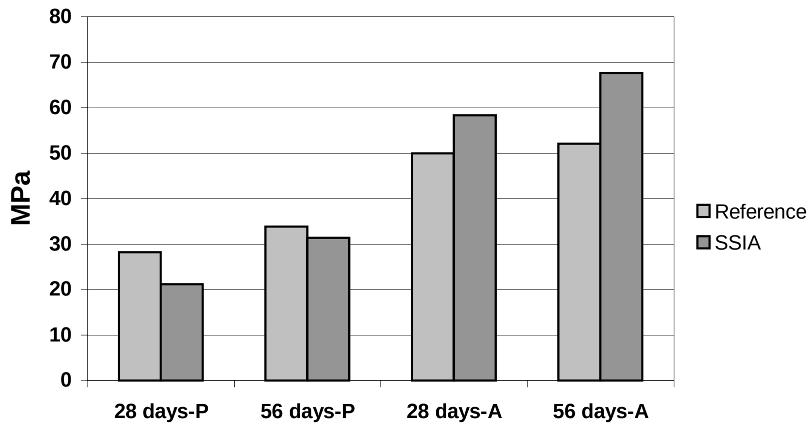

Fig. 3. Strengths for reference concretes and concretes with SSIA for passive and aggressive environmental class. P: Passive environmental class, A: Aggressive environmental class, SSIA: Sewage sludge combustion ash

Table 1 Mix design characteristics for concretes in passive environmental class SSIA: Sewage sludge incineration ash, FA: Fly ash, SF: Silica fume, SPT: Superplasticizer, KD: Kiln dust

	PR Reference	P2 50 % FA + 10 % KD	P3 17 % SSIA	P5 Concrete slurry	P6 100 % stone dust	P7 30 % FA from biofuels
Cement, kg/m^3	143	90	137	141	267	191
FA, kg/ m^3	51	128	15	52	-	-
SF, kg/m^3	10	14	10	10	-	-
SPT, kg/m^3	-	1.1	3.2	-	1.8	1.9
Equiv. w/c	0.73	0.66	0.78	0.77	0.72	0.69

Table 2 Evaluation of environmental goals and intentions and compressive strength goals for concretes in a passive environmental class SSIA: Sewage sludge incineration ash, FA: Fly ash, KD: Kiln dust

Passive environmental class					
Name	P2 50 % FA + 10 % KD	P3 17 % SSIC	P5 Concrete slurry	P6 100 % stone dust	P7 30 % FA from biofuels
Environmental goal					
• CO_2	37% √	-	-	-	30% √
• Residual product as aggregate	-	-	-	42% √	-
• Own residual product	-	-	√	√	-
• New type of residual product	-	√	-	-	√
• Waste-derived fuels	√	√	√	√	√
Environmental intentions	√	Wastewater quality? (Zn, V)	Wastewater quality? (Zn, Pb, Cu, P_2O_5)	√	Wastewater quality? Recycling? (chloride)
Compressive strength					
28-day, Mpa	26 √	21 √	23 √	29 √	28 √
56-day, MPa (% of reference concrete)	34 (100) √	31 (93) √	27 (80) √	33 (97) √	32 (94) √

Table 3 Mix design characteristics for concretes in an aggressive environmental class SSIA: Sewage sludge incineration ash, FA: Fly ash, SM: Silica fume, SPT: Superplasticizer, CREP: Cement with reduced environmental impact

	AR Reference	A0 CREP	A1 40 % FA + CREP	A3 10 % SSIA + CREP	A5 Concrete slurry	A6 50 % stone dust
Cement, kg/m^3	288	287	189	277	398	397
FA, $kg/\ m^3$	34	32	137	-	-	-
SF, kg/m^3	17	17	18	17	-	-
SPT, kg/m^3	-	-	3.4	3.2	4.0	6.8
Equiv. w/c	0.45	0.47	0.46	0.45	0.38	0.37

Table 4 Evaluation of environmental goals and intentions and compressive strength goals for concretes in an aggressive environmental class SSIA: Sewage sludge incineration ash, FA: Fly ash, CREP: Cement with reduced environmental impact

Aggressive environmental class					
Name	A0 CREP	A1 40 % FA + CREP	A3 10 % SSIA + CREP	A5 Concrete slurry	A6 50 % stone dust
Environmental goal					
• CO_2	27% (√)	52 % √	29 % (√)	-	-
• Residual product as aggregate	-	-	-	-	20 % √
• Own residual product	-	-	-	√	√
• New type of residual product	-	-	√	-	√
• Waste-derived fuels	√	√	√	√	√
Environmental intentions	√	√	Wastewater quality? (Zn, Pb, Cu, P_2O_5)	√	√
Compressive strength					
28-day, Mpa	51 √	58 √	58 √	64 √	62 √
56-day MPa, (% of reference concrete)	58 √ (112)	61 √ (117)	68 √ (130)	68 √ (130)	63 √ (121)

Table 5 Chemical composition of sewage sludge incineration ash (from Lynette Fællesskabet) and of fly ash from coal combustion (Danaske type B1). DM: Dry-matter.

Chemical analysis	Unit	Sewage sludge incineration ash	Fly ash from coal combustion
CaO	% DM	16,85	2,78
SiO_2	% DM	28,44	59,74
Fe_2O_3	% DM	13,89	7,57
Al_2O_3	% DM	7,90	21,31
TiO_2	% DM	1,61	0,98
P_2O_5	% DM	19,62	0,34
MgO	% DM	3,07	1,35
Chloride	% DM	0,098	0,004
SO_3	% DM	1,85	0,65
K_2O-total	% DM	2,54	0,65
Na_2O total	% DM	1,36	0,52
Na_2O-equiv. Total	% DM	3,03	1,84
Cr	mg/kg	136	137
Zn	mg/kg	2810	181
Pb	mg/kg	534	34
Cu	mg/kg	971	77
Ni	mg/kg	109	100
V	mg/kg	61	268
Co	mg/kg	49	32
Mn	mg/kg	566	313
Tl	mg/kg	<20	<20
Cd	mg/kg	<10	<10
As	mg/kg	<30	<30
Hg	mg/kg	0,4	0,2
Loss on ignition	% DM	3,04	3,37
Water content	%	9,2	0,3

Table 6 Results of frost testing according to a revised version of SS 13 72 44 for A3 concrete with sewage sludge incineration ash and cement with reduced environmental impact, (8)

Age of test specimens at start of testing	28-days	56-days	56-days/28-days
31 days, kg/m^3	0.0477	0.0693	1.45
59 days, kg/m^3	0.0921	0.1762	1.91
Carbonated (59 days), kg/m^3	0.0715	0.2206	3.08
Requirement, kg/m^3	-	<0.2	-
Alternative requirement, kg/m^3	-	<0.5	<2

Table 7 Structural Components used for the Assessment of Environmental Effects of Concrete Bridges ("Green" Concrete and/or "Green" Design Details)

Structural component	Concrete type	Supplementary protection	Expected service life
Bridge deck	Green concrete	Waterproofing membrane	Short
		Top layer of high-strength mortar 1)	Medium to long
		Top layer (35 mm) of fibre reinforced concrete 1)	Medium
Column	CRC 2)	None	Long
	Green concrete	None	Medium
		Covering of stainless steel	Long
Edge beam	Green concrete	None	Short to medium

1) Without waterproofing membrane 2) CRC-Compact Reinforced Concrete.