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Green Concrete in Denmark

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Synopsis: Cement and concrete may have an important role to play in enabling Denmark to fulfil its obligation, agreed at the Kyoto conference, to reduce the total CO_2 emission by 21 % compared to the 1990-level before 2012. This is because approximately 2 % of Denmark's total CO_2 emission stems from cement and concrete production.

There is considerable knowledge about how to produce concrete with a reduced environmental impact. However, it is not known to a sufficient degree - neither in Denmark nor internationally - on what scale, and with what technology, this "green" concrete can be applied in practice in buildings and structures. For instance, there is not enough information about how the properties of green concrete, such as compressive strength, durability, fire performance, casting and execution, hardening, and curing are affected by the measures to reduce the environmental impact of concrete.

This paper gives an overview of the present state of affairs in Denmark of concrete types that have reduced environmental impact, including the use of low energy cement, recycling of crushed concrete as aggregate, the use of fly ash and micro silica, etc. There is a description of among other things the possibilities of using "green" concrete within the existing standards and specifications, and Danish and European research projects about green concrete, life cycle assessments, etc. A special focus will be on a large Danish centre running from 1998-2002, involving leading universities, institutes, building owners, contractors, consultancies, and cement and concrete manufacturers.

The potential environmental benefit to society of being able to build with "green" concrete is huge. It is realistic to assume that technology, which can halve the CO_2 emission related to concrete production, can be developed. This will potentially reduce Denmark's total CO_2 emissions by ½ % and contribute significantly to achieving the targets set up at the Kyoto Conference.

Keywords: Kyoto conference, Green concrete, Concrete mix design, Packing calculation, Demo bridge, Specifications, Environmental management, Life cycle assessment, Cleaner technologies.

1.0 CEMENT AND CONCRETE'S ROLE IN MEETING THE ENVIRONMENTAL OBLIGATIONS

Cement and concrete may have an important role to play in enabling Denmark to fulfil its obligation to reduce the total CO_2 emission by 21 % compared to the 1990-level before 2012, as agreed at the Kyoto conference.

This is because the volume of concrete consumption is large in Denmark. Approx. 1.5 tonnes of concrete per capita are produced annually. The CO_2 emission related to concrete production, inclusive of cement production, is between 0.1-0.2 tons per ton produced concrete. This corresponds to a total quantity of CO_2 emission of 0.6 - 1.2 m tons per year. Approximately 2 % of Denmark's total CO_2 emission stems from cement and concrete production.

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 total CO_2 emission by 0.5 %.

The somewhat soft demands in the form of environmental obligations result in rather specific technical requirements for the industry - including the concrete industry. These technical requirements include among others new concrete mix designs, new raw materials, and new knowledge (practical experience and technical models) about the properties of the new raw materials and concrete mix designs.

2.0 DANISH AND EUROPEAN ENVIRONMENTAL POLICIES

The latest proposal from the Ministry of Environment and Energy, Danish Environmental Protection Agency (1) for a future environmental policy, is based on a product-effect approach. The proposal is based on the argument that the total environmental impact can only be understood correctly - and the activities be prioritised correctly - if the entire life cycle of the products are considered. The goal of this approach is to increase the development, production, and sale of products with minor environmental impacts instead of existing, more environmentally damaging products.

The proposal is in accordance with the International and European Conventions and Protocol, which Denmark has joined, and with the nationally agreed goals that comply with these. An important aspect is Denmark's obligation to reduce the CO_2-emission as previously mentioned.

The proposal covers the following environmental aspects: Greenhouse effect, depletion of the ozone layer, photochemical oxidation, eutroplication, acidification, materials harmful to the environment and health, water and resources.

Discussions with the Ministry of Environment and Energy, Danish Environmental Protection Agency have resulted in the following priorities regarding environmental impacts relevant to concrete (2).

High priority

- CO_2
- Resource (water)
- Fossil fuel (oil, coal)
- Substances harmful to health or environment (chemicals, heavy metals)

Medium priority

- SO_2 and NO_X
- Local supply of resources such as sand, stone, gravel, chalk and lime
- Resource (recycling of waste)

Low priority

- Volatile Organic Compounds (only relevant to the working environment)

The above mentioned priorities have been included in a large European project about cleaner technologies in the life cycle of concrete products (TESCOP), described in detail in chapter 4. Furthermore, priorities have been made for the other participating countries, i.e. Greece, Italy, and The Netherlands, and for Europe and the International World. Even though there are differences in the political environmental priorities, all agree that the five environmental impacts given highest priority are (2):

- CO_2
- Energy
- Water
- Minimisation of waste/increased reuse and recycling/use of secondary raw materials
- Substances harmful to health or environment

The environmental policies in recent years have been implemented in different ways showing that environmental aspects are, and will be, more and more important in the building and construction industry. More and more tenderers make specified environmental demands, in addition to "usual" concrete demands for their contractors, e.g. the Danish Road Directorate has formulated environmental strategies which will later be specified as requirements.

Recently, a handbook has been prepared for consulting engineers as an aid to environmentally correct design (4). The handbook has been used for 15 demonstration-projects, among these the design of a highway bridge and the maintenance of a railway bridge.

3.0 State of affairs of concrete with reduced environmental impact

There is considerable knowledge in Denmark about how to produce concrete with lower environmental impact, so-called green concrete.

The concrete industry in Denmark has considerable experience in dealing with environmental aspects. The concrete industry realised at an early stage that it is a good idea to be in front with regard to documenting the actual environmental aspects and working on improving the environment, rather than being forced to deal with environmental aspects due to demands from authorities, customers and economic effects such as imposed taxes, etc.

Furthermore, some companies in the Danish concrete industry have recognised that reduction in production costs often go hand in hand with reduction in environmental impacts. A Danish concrete element manufacturer has achieved significant economic savings by dividing the waste into different fractions and thereby increasing the recyclability. Thus, environmental aspects are not only interesting from an ideological point of view, but also from an economic aspect.

The knowledge and experience in Denmark, about how to produce concrete with lower environmental impacts can be divided into two groups, concrete mix design and cement and concrete production:

Concrete mix design:

- using cement with reduced environmental impacts
- minimising cement content
- substituting cement with pozzolanic materials such as fly ash and micro silica
- recycling of aggregate
- recycling of water

Cement and concrete production:

- environmental management

3.1 Concrete mix design

The type and amount of cement has a major influence on the environmental properties of a concrete. An example of this is shown in figure 1, where the energy consumption in MJ/kg of a concrete edge beam through all the life cycle phases is illustrated. The energy consumption of cement production make up more than 90 % of the total energy consumption of all constituent materials and approximately 1/3 of the total life cycle energy consumption.

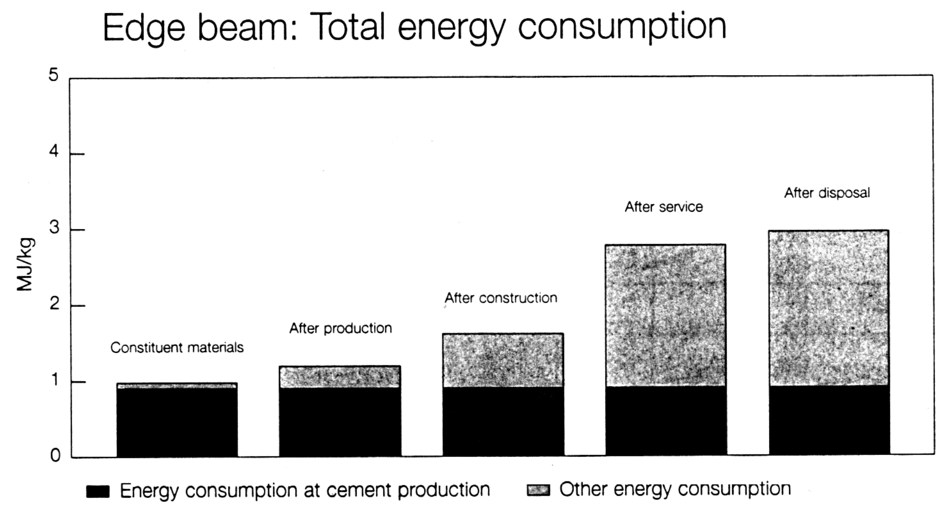

Figure 1. Edge beam: Total energy consumption through all the life cycle phases (5)

By selecting a cement type with reduced environmental impacts, and by minimising the amount of cement the concrete's environmental properties are drastically changed. This must, however, be done whilst still taking account of the technical requirements of the concrete for the type and amount of cement. Denmark's cement manufacturer, Aalborg Portland, prioritises development of cements with reduced environmental impacts (6).

One method of minimising the cement content in a concrete mix is by using packing calculations to determine the optimum composition of the aggregate. A high level of aggregate packing reduces the cavities between the aggregates, and thereby the need for cement puste. This results in better concrete properties and a better environmental profile, due to a smaller amount of cement. When having experimentally determined the packing, the density, and the grain size distribution of each aggregate material, it is possible to calculate the packing of any combination of aggregates using DTI Concrete Centre's computer program (7).

Another way of minimising the cement content in a concrete is to substitute parts of the cement with other pozzolanic materials. In Denmark, it is common to produce concrete with fly ash and/or micro silica. Both of these materials are residual products (from production of electricity and production of silicon, respectively) and both have a pozzolanic effect. Thus, a material with large environmental impact, i.e. the cement, is substituted with materials with reduced environmental impacts.

The restrictions on adding fly ash and micro silica laid down in the future Danish concrete materials standard (8), will be as shown in table 1.

The activity index will be 0.5 for fly ash and 2.0 for micro silica (8), in the future standard, which is scheduled to be completed by the end of 1998.

	Passive environmental class	Moderate environmental class	Aggressive environmental class	Extra Aggressive environmental class
Max. content of FA+MS in % of C+FA+MS	no requirements	35	25	25
Max content of MS in % of C+FA+MS	no requirements	10	10	10

C=cement, FA= Fly Ash, MS= Micro Silica

Environmental classes:

Passive: dry atmosphere with no risk of corrosion.

Moderate: moist atmosphere, with no risk of frost combined with water saturation, and with no significant alkaline and/or chloride influence on the concrete surface.

Aggressive: moist atmosphere, with significant alkaline and/or chloride influence on the concrete surface or where there is risk of water saturation combined with frost.

Extra Aggressive: moist atmosphere, with significant alkaline or/and chloride influence or layering on the concrete surface

Table 1, Requirements on the content of fly ash and micro silica according to the future Danish concrete materials standard (8)

In order to reduce the consumption of raw materials and to minimise the waste generated from demolished concrete structures, surplus, and production errors, crushed concrete can be reused as aggregate in Denmark.

There exists a recommendation for recycled concrete aggregate from 1990 with an appendix from 1995 published by the Danish Concrete Association (9) and (10). Currently, a new concrete standard is being prepared - as previously mentioned (8). It is expected that the use of recycled aggregate in concrete, for passive environmental class will be allowed. See table 1 for definition of environmental classes.
Also recycled water, initially used for washing out the aggregates from surplus concrete and cleaning the production equipment, is expected to be allowed in the new Danish concrete standard.

3.2 Cement and concrete production

It is also possible to reduce a concrete's environmental impact by reducing the environmental impacts in cement and concrete production. The Danish cement manufacturer has many activities concerned with the reduction of environmental impacts (6).

As regards concrete production, experience with reductions of primarily water consumption, energy consumption and waste production is available. Even though the contribution of concrete production to a concrete type's environmental profile is minor, it does give a contribution, and it is important - environmentally and economically - to the single concrete producer.

In a large Danish project, "Environmental management in the building and construction industry", a guide to environmental reading, environmental management based on the ISO 14001 standard, and a "get-started" guide are under preparation. The guide can help the concrete producers reduce environmental impacts from their production (11), (12), and (13).

4.0 EUROPEAN PROJECT "CLEANER TECHNOLOGY SOLUTIONS IN THE LIFE CYCLE OF CONCRETE PRODUCTS" (TESCOP)

The TESCOP project is a so-called Brite Euram project with 50 % funding from the EU Commission, (3). The duration of the project is three years from March 1997 to March 2000. The partners in the project are: Danish Technological Institute Concrete Centre (Project Manager), Aalborg Portland (the Danish cement manufacturer), the Danish Concrete Element Association and partners in Greece, Italy, and The Netherlands. For further details on the partners, see chapter 6 "Overview of environmental activities in Denmark related to concrete".

The main objective of the project is to develop and implement cost-effective cleaner technologies to reduce the environmental taxes and fulfil environmental requirements in the concrete industry and to reduce the environmental impact of concrete products.

The concrete industry covers all partners in the life cycle of concrete - spanning from extraction and processing of component raw materials over concrete manufacturing, rebuilding/extension of buildings and constructions, operation and maintenance of buildings and constructions to demolition and waste treatment/recycling.

Environmental data has been collected for 12 concrete products, and currently LCAs are being made. In parallel to this, a survey of existing cleaner technologies is made with the purpose of exchanging and adjusting existing cleaner technologies between the European countries. Furthermore, the preparation of a survey of existing cleaner technologies will ensure that already developed cleaner technologies will not be re-developed. Scenarios prepared in the form of a priority list are described, see chapter 2 "Danish and European environmental policies". The LCAs and the political scenarios form the basis for the selection of areas where cleaner technologies should be developed.

Among others, the following cleaner technologies will be developed:
- Self-compacking concrete
- Water saving and pH-regulation
- Environment friendly form oils
- High alkali dust – cement production
- Belite rich clinker – cement production
- Selective demolition techniques
- Chemical in admixtures and repair-products.

The cleaner technologies will be evaluated with regard to economy so they are cost-effective and with regard to environmental impact, so it does not cause more environmental impact to introduce them than they save. The developed cleaner technologies will be tested preferably in full-scale.

5.0 DANISH CENTRE FOR GREEN CONCRETE

In Denmark, there is considerable knowledge about how to produce concrete with a reduced environmental impact. However, it is not known to a sufficient degree - neither in Denmark nor internationally - on what scale, and with what technology, this "green" concrete can be applied in practice in buildings and structures. For instance, there is not enough information about how the properties of green concrete, such as compressive strength, durability, fire performance, casting and execution, hardening, and curing, are affected by the measures to reduce the environmental impact of concrete. This is the background for the large Danish centre called Green Concrete.

The most important goal of this centre is to develop the technology necessary to produce resource saving concrete structures by means of new binding materials - in new concrete combined with a possible reuse of materials. It is the plan to reach the goal by developing the necessary technology for all phases of the design of resource saving concrete structures. This applies to the design of structure, the specification, the manufacturing, the performance, the operation, and the maintenance.

The centre involves leading universities, institutes, building owners, contractors, consultants and cement and concrete manufacturers, see chapter 6 “Overview of environmental activities in Denmark related to concrete”.

5.1 One of the largest Danish concrete development projects

The centre has a budget of approx. DKK 22 m (Approximately US$ 3.5 m) - one of the largest Danish concrete development projects ever. The Danish Agency for Trade and Industry is financing DKK 9.6 m. The industry partners are financing their own contribution, and the Concrete Centre is financing 25% of their contribution.

The centre started 1st July, 1998 and runs for four years.

5.2 Environmental goals

The centre’s preliminary environmental goals which green concrete has to fulfil are as follows:
- Reduction of CO_2 emissions by 21 %. This is in accordance with the Kyoto obligation as described previously.
- Increase the use of inorganic residual products from industries other than the concrete industry by approx. 20 %.
- Reduce the use of fossil fuels by increasing the use of waste derived fuels in the cement industry. The reduction percentage has not yet been determined.
- Avoid the use of materials from the list of unwanted materials prepared by the Danish Environmental Protection Agency. These materials can for instance be form oil and additives.
- The recycling capacity of the green concrete must not be less compared to existing concrete types.
- The production of green concrete must not reduce the recycling applicability of the discharged water.
- The production and the use of green concrete must not deteriorate the working environment.

5.3 Three different ways to produce green concrete

In three different development projects in the centre, green concrete is examined in three different ways:

1. To minimise the clinker content, i.e. by replacing cement with fly ash, micro silica in larger amounts than are allowed today, or by using extended cement, i.e. Portland limestone cement. The preliminary plan is to analyse concrete for passive environmental class with fly ash amounts of up to 60% of the total amount of cement and fly ash, concrete for aggressive environmental class with Portland limestone cement, and concrete for passive environmental class with dry desulphurization products.
2. To develop new green cements and binding materials, i.e. by increasing the use of alternative raw materials and alternative fuels, and by developing/improving cement with low energy consumption. A new, rapid hardening low energy cement based on mineralized clinker is currently ready for testing.
3. Concrete with inorganic residual products (stone dust, crushed concrete as aggregate in quantities and for areas that are not allowed today) and cement stabilised foundation with waste incinerator slag, low quality fly ash or other inorganic residual products. Currently an information-screening of potential inorganic residual products is carried out. The products are described by origin, amounts, particle size and geometry, chemical composition and possible environmental impacts. From this information-screening approximately 5 products will be selected and analysed for use in green concrete. Approximately 3-5 materials will be selected for testing in cement stabilised foundations.

All the above mentioned green concrete types will be tested for workability, changes in the workability after 30 minutes, air content, compressive strength development, E-modules, heat development, homogenity, water separation, setting, density, and pumpability. Furthermore, the water/cement ratio, water/binder ratio, and the chloride content will be calculated.

From the tests, the most promising green concrete will be selected and exposed to more advanced testing.

5.4 Design, operation and maintenance, research activities, and the construction of a demonstration bridge

In another development project under the research project, the operation and maintenance of green concrete structures are analysed, and in another development project, green structure solutions and structure solutions for green concrete are developed.

Other activities concerned with specific topics include more profound research and developing. This includes examination of mechanical properties, fire resistance, execution, durability and physical and thermal dynamic examinations.

The results are expected to be implemented in a Road Directorate special concrete specification for resource saving concrete structures. This will be used in carrying out a demonstration project which includes the dimensioning and construction of a bridge in green concrete.

6. OVERVIEW OF ENVIRONMENTAL ACTIVITIES IN DENMARK RELATED TO CONCRETE

Title	Industry analysis concrete - Cleaner Technology in concrete production.
Purpose	Environmental overview over concrete. LCA for selected products.
Participants	Carl Bro Group, DTI Concrete Centre and the industry.
State of affairs	The project is completed. Reports on the project can be obtained from the Danish Environmental Protection Agency.

Title	Guidance in specification of environmental parameters.
Purpose	To set up a guide making the pre-cast concrete element producers able to collect and estimate the environmental parameters.
Participants	Polish trainee. Danish Pre-cast Concrete Federation, Betonelement a/s, DTI Concrete Centre.
State of affairs	The project is completed. The guide is available in a provisional English version.

Title	Summary of environmental impacts - Unicon factories.
Purpose	To prepare a summary of energy and water consumption in all Unicon’s ready-mix concrete factories and to analyse the causes of differences.
Participants	Polish trainee, Unicon Beton and DTI Concrete Centre.
State of affairs	The project is completed. Internal report available.

Title	Green taxes, importance to the members of Danish Pre-cast Concrete Federation.
Purpose	A survey of the economic consequences of the government’s green taxes for the members of Danish Pre-cast Concrete Federation.
Participants	DTI Concrete Centre.
State of affairs	The project is completed. Internal report available.

Title	Environmental management in the building and construction industry.
Purpose	To prepare a guide to enable individual companies to introduce environmental management.

Participants	8 industries and trade organisations in the building and construction industry including Joint Association of Concrete Industry, DTI Productivity Centre (Project Manager), DTI. Concrete Centre is consultant.
State of affairs	The project started in autumn 1996 and lasts for two years.

Title	Environmental concrete design. Partial project. Environmental data for building materials.
Purpose	To prepare a work of reference with environmental information on the life cycle of many materials, including concrete.
Participants	Danish Building Research Institute (Project Manager), Danish Association of Consulting Engineers, DTI Concrete Centre and others.
State of affairs	The project is completed. Report can be obtained from the Centre for Building Planning Systematics, DTI Building Technology.

Title	Environmental screening of outlet components of different materials (PVC, HDPE, PP and concrete) in the life cycle.
Purpose	To explain the environmental impacts from cradle to grave of outlet components of PVC, HDPE, and concrete primarily based on existing data.
Participants	DTI Centre for Environmental Technology (Project Manager), DTI Concrete Centre, Hvorslev Consult and the plastic industry.
State of affairs	The project was started in October 1996 and completed in May 1998.

Title	Cleaner Technology Solutions in the Life Cycle of Concrete Products.
Purpose	To develop cleaner technology in the life cycle of concrete products.
Participants	Danish Pre-cast Concrete Federation, Aalborg Portland, DTI Concrete Centre (Project Manager), and other European partners.
State of affairs	The project was started at the beginning of 1997 and lasts for three years.

Title	“Swan” marking (Svanemærket) of concrete.
Purpose	To manage the concrete industry’s interests in relation to the “Swan” mark of concrete.
Participants	Chr. F. Justesen, Aalborg Portland and Jacob Bjerre, GH Beton is participating in the group of experts, who will determine the criteria for concrete. DTI Concrete Centre is the secretary of the industry.
State of affairs	The project was started in December 1997 and completed in 1998, when the “swan” marking was excluded from concrete.

Title	Danish Concrete Society’s work group on environmental use of concrete.
Purpose	To collect and organise existing knowledge about environmental use of concrete.
Participants	Moe & Brødsgaard (Chairman), DTI Concrete Centre, Cowi, Dansk Betonindustri-forening, Aalborg Portland, GH Beton, Demex, J&B.
State of affairs	The project was started in January 1998 and is expected to be completed at the end of 1998.

Title	Environmental project for light clinker concrete.
Purpose	To collect and evaluate environmental data for the life cycle of light clinker concrete and to prepare a guide to enable the producers to collect and estimate environmental data.
Participants	DTI Concrete Centre, Concrete Block Section and Light-weight Element Section, The Danish Concrete Industry Association.
State of affairs	The project was started in May 1998 and is expected to be completed at the end of 1998.

Title	Resource saving concrete structures (Green Concrete).
Purpose	To develop the necessary technology to manufacture and use green concrete.
Participants	DTI Concrete Centre (project co-ordinator), Aalborg Portland A/S (head of the steering committee), COWI, Højgaard & Schultz A/S, The Danish Road Directorate, Unicon Concrete

	I/S, Technical University of Denmark, Aalborg University, AB Sydsten
State of affairs	The project was started 1 July 1998 and will run for 4 years.

7.0 CONCLUSION

The overview of the present state of affairs in Denmark of concrete types with reduced environmental impact has shown that there is considerable knowledge and experience on the subject. The Danish and European environmental policies have motivated the concrete industry to react, and will probably also motivate further development of the production and use of concrete with reduced environmental impact.

The somewhat vague environmental requirements that exist have resulted in a need for more specific technical requirements, and this is the focus of a recently started, large, Danish research project, where the most important goal is to develop the technology necessary to produce and use resource saving concrete structures, i.e. green concrete. This applies to structure design, specification, manufacturing, performance, operation, and maintenance.

The potential environmental benefit to society of being able to build with green concrete is huge. It is realistic to assume that the technology can be developed, which can halve the CO_2 emission related to concrete production, and with the large energy consumption of concrete and the following large emission of CO_2 this will mean a potential reduction of Denmark's total CO_2 emission by ½ -1%.

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