NCR 37
RESEARCH PROJECTS 2008

NORDIC CONCRETE RESEARCH

PROCEEDINGS
NORDIC CONCRETE RESEARCH

STOCKHOLM, SWEDEN 2008

EDITED BY: JOHAN SILFWERBRAND

PUBLISHER: NORSK BETONGFORENING
POSTBOKS 2312 SOLLI
N-0201 OSLO

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The Use of Fly Ash from Co-combustion in the Production of Concrete

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Key words: Fly ash, co-combustion, straw, wood pellets, concrete production

1. INTRODUCTION

In Denmark the production of electricity is largely dependent on coal fired power plants. With the emergence of the EN 450-1 standard fly ashes from co-combustion of coal and certain organic materials in limited amounts were allowed in concrete production on the same conditions as fly ash from pure coal combustion [1]. In the Netherlands concrete production has been allowed based on an ETA approval of fly ash from co-combustion with substantially higher amounts of co-combustion material than is allowed according to EN 450-1 [2]. The Danish government wants the national power plants to use considerable amounts of biomass in the production of electricity and heat. In order to fulfil the agreement with the government the Danish power plants have looked into producing co-combustion fly ashes without compromising the quality of the fly ash in terms of its properties for use in concrete production.

2. MATERIALS AND METHODS

Two general types of ashes were investigated, i.e. ash from co-combustion of coal with straw from agriculture and ash from co-combustion of coal with wood pellets from the wood industry. The bulk chemical composition of ashes was determined and the chemical and physical test required to conform to EN 450-1 were performed. In addition pre-testing, i.e. the fresh and hardened concrete properties were determined, according to EN 206-1 [3] was performed on two typical Danish fly ash concrete mixtures in strength classes C20 and C35 corresponding to exposure classes X0, XC1 and XD1, XS2, XF3, XA2, respectively.

3. RESULTS

The activity indexes of tested fly ashes are shown in Table 1. The activity indexes of the co-combustion fly ashes are very similar to those of the reference ashes, and all ashes meet the requirements to activity index of EN 450-1, i.e. 75 % at 28 days and 85 % at 90 days. The strength developments of the reference pure coal fly ash concretes and the co-combustion fly ash concretes are shown in Table 2 and 3. From the tables it can be seen that strengths obtained with the co-combustion ashes are all within their strength classes. However, in some cases the co-combustion fly ash concrete yielded strengths that were lower than those of the reference concretes, which can, at least to some extend, be attributed to higher air contents of co-

combustion fly ash concretes. Where the air contents of the reference and co-combustion fly ash concretes were the same the strengths were also the same.

Table 1 – Activity indexes of fly ashes.

Ash ID	Co-combusition material	Co-combustion load (%-wt)	Activity index (%)	
			28 days	90 days
StrawREF	none	0	88	103
Straw10	straw	10	95	110
Straw14	straw	14	86	97
WoodREF	none	0	84	99
Wood10	wood pellets	10	81	98

Table 2 – Strength development of C35 concretes in exposure class XF3 (equivalent w/c = 0.42)

Ash ID	Co-combusition material	Co-combustion load (%-wt)	Compressive cylinder strength (MPa)			
			2 days	7 days	28 days	56 days
StrawREF	none	0	23.4	35.0	54.7	56.0
Straw10	straw	10	22.9	32.1	45.8	49.1
Straw14	straw	14	19.6	31.5	43.9	48.5
WoodREF	none	0	25.1	38.5	53.9	56.4
Wood10	wood pellets	10	21.4	34.0	47.4	51.3

Table 3 – Strength development of C20 concretes in exposure class X0 (equivalent w/c = 0.71)

Ash ID	Co-combusition material	Co-combustion load (%-wt)	Compressive cylinder strength (MPa)			
			2 days	7 days	28 days	56 days
StrawREF	none	0	6.5	11.7	22.1	28.1
Straw10	straw	10	6.5	11.4	21.9	28.2
Straw14	straw	14	5.7	11.0	19.0	24.3
WoodREF	none	0	6.0	12.6	26.0	31.5
Wood10	wood pellets	10	6.2	12.5	25.8	31.2

4. CONCLUSION

The results from testing of co-combustion fly ashes, based on straw from agriculture and wood pellets from the wood industry, showed that the co-combustion ashes performed similarly to the pure coal ashes in typical Danish ready mixed concrete.

The Danish concrete industry has been using the straw-based co-combustion ash for more than 3 years, and the practical experience confirms that this co-combustion ash has a performance equivalent to that of pure coal ash.

The co-combustion ash based on wood pellets has not yet been started up in daily production.

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Session I1 – I2
Industrial Day

COIN – Concrete Innovation Centre

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Keywords: Concrete, research, innovation, attractiveness

1. INTRODUCTION

COIN – Concrete Innovation Centre (www.sintef.no/coin) – is one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and structures. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

2. RESEARCH SIGNIFICANCE

A major challenge facing the concrete industry is the paradox that it is an essential necessity but yet has a low public image. Hence, it is an important issue for the industry to create a more realistic and positive image of its products. It is likewise important to make concrete buildings more attractive in order to gain a stronger position among building owners, architects, contractors and in the public opinion, and thereby increasing the marked share especially on housings. A goal is therefore to improve the quality of concrete products and to make it even more cost efficient and environmentally friendly.

The productivity in the construction sector has during the past decade for several reasons had a negative development compared with other industries. Technical improvements may significantly reduce the required work force and counteract this trend. In order to further improve the product quality, productivity and the work environment there will inevitably be an increased trend towards tailoring of properties and a higher degree of (indoor) prefabrication and premixed products. A goal is therefore to develop more rational production and to increase the level of competence in this sector.

Sustainable development will still be emphasized by European and National politicians in the coming years. The sustainability of buildings and structures is strongly influenced by the choices made in design and construction, and it should be evaluated for the whole service life of the building. Recent studies reveal the possibilities for significant reductions (>50 %) in energy consumption for heating and cooling of buildings by adequate utilisation of the high thermal energy of concrete. A goal is to develop designs and construction systems for significant reductions in energy consumption for heating and cooling of buildings by adequate utilisation of the high thermal energy of concrete.

With respect to sustainability the concrete industry also faces challenges related to environmental impact, depletion of resources and energy consumption. Being a "natural" material, utilization of concrete implies consumption of a vast amount of raw materials. Thus, the industry is facing rapidly increasing challenges related to global environmental requirements and supply of resources that force the concrete industry to look for alternative solutions. A goal is therefore to improve the sustainability through development of technologies for reduced raw material and energy consumption and for low emissions, while maintaining the market share.

Aggregates for concrete have been quarried from natural resources. Now, an increasing amount is produced from crushed rock (but also secondary raw material, demolition waste, etc) because the natural resources are emptied or rejected for environmental reasons. However, even rock quarries meet environ-mental restrictions all over Europe. Production of cement is associated with high CO_2-emission. Although considerable progress has been made in optimisation and utilization of alternative materials and fuels, it still accounts for about 5 % of the world's total CO_2-emissions. To meet these environmental challenges the concrete industry needs to reduce material consumption, develop alternative and more robust materials, lighter products, new construction and design techniques.

3. CONTENT AND RESULTS

The work so far has been to organize the Centre and to establish State-of-the-Art within the chosen research areas. The latter has resulted in nearly 30 State-of-the-Art Reports, many of them presented at the present symposium. About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology – NTNU (research partner) and industry partners, 15 – 20 PhD-students, 5 – 10 MSc-students every year and a number of international guest researchers, work on presently 5 projects: 1. Advanced cementing materials and admixtures, 2. Improved construction techniques, 3. Innovative construction concepts, 4. Operational service life design, and 5. Energy efficiency and comfort of concrete structures.

4. PROJECT DATA AND FINANCIAL SUPPORT

COIN has presently a budget of NOK 200 million over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %). The present industrial partners are: Aker Kværner Engineering and Technology, Borregaard LignoTech, Maxit Group, Norcem A.S, Norwegian Public Roads Administration, Rescon Mapei AS, Spenncon AS, Unicon AS and Veidekke ASA.

Future Living in Concrete Houses

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Key words: Future living, concrete houses.

1. INTRODUCTION

Residential buildings are not always adjusted to the way we live our lives today. Our houses are still built as they have been for ages although our way of living has changed a lot in the last decades. Today it is common that both parents are working full time and do not have much time to spend on housework or to keep the house well-maintained. The circumstances in a family may not be the same forever or they can be very different from one family to another. This means that we have to be able to build flexible houses which can satisfy sudden changes in needs connected to the living environment.

These thoughts initiated this concrete house-project KONKRET VISION (eng. Concrete Vision).

2. THE NETWORK BETTAN AND OUR PROJECT *KONKRET VISION*

The ideas for this house in concrete is based upon the desires of the women in the female network Bettan in the Swedish Concrete Association. The network was inspired by Volvo's "Your Concept Car – by Women for Modern People". This project is financed by the Swedish National Board of Housing, Building and Planning and by the Development Fund of the Swedish Construction Industry. The project will in June 2008 result in blueprints and computer visualizations of a two-storey concrete house.

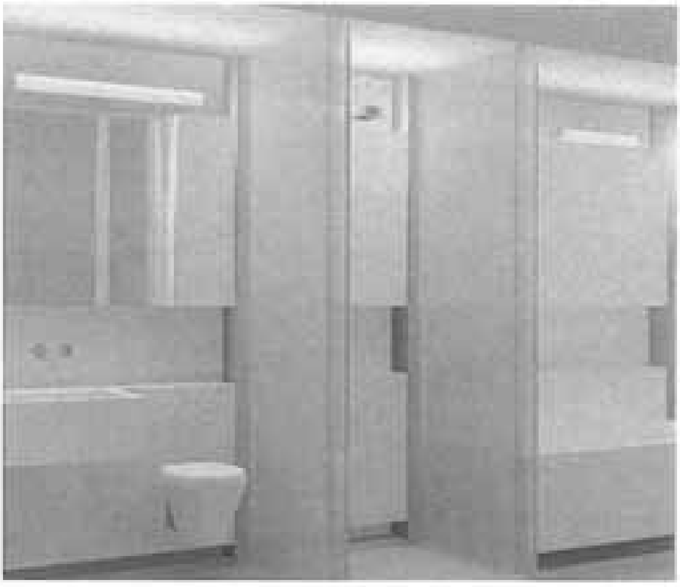
The female network Bettan was founded in spring 2004. The purpose of this network is to attract more women to the construction industry and to make the industry more competitive. Today, in Sweden, only 8 percent of all white-collar workers and 1 percent of all carpenters are women, respectively.

The goal is to develop a living environment where sharp solutions, good functions and quality in the housing is given priority. In this project we try to think outside the box to be able to create a safe housing with wellbeing that simplifies our living and protects our environment.

3. ENERGY EFFICIENCY – KIND TO YOUR WALLET AND TO THE ENVIRONMENT

We focus to create an energy efficient and environmental friendly house. These factors control the design of the house, the orientation in different point of compass, choice of climate control system and of course also in choice of materials. In order to create an energy efficient house we give priority to, among other things, a well insulated concrete structure, energy efficient windows and renewable energy source.

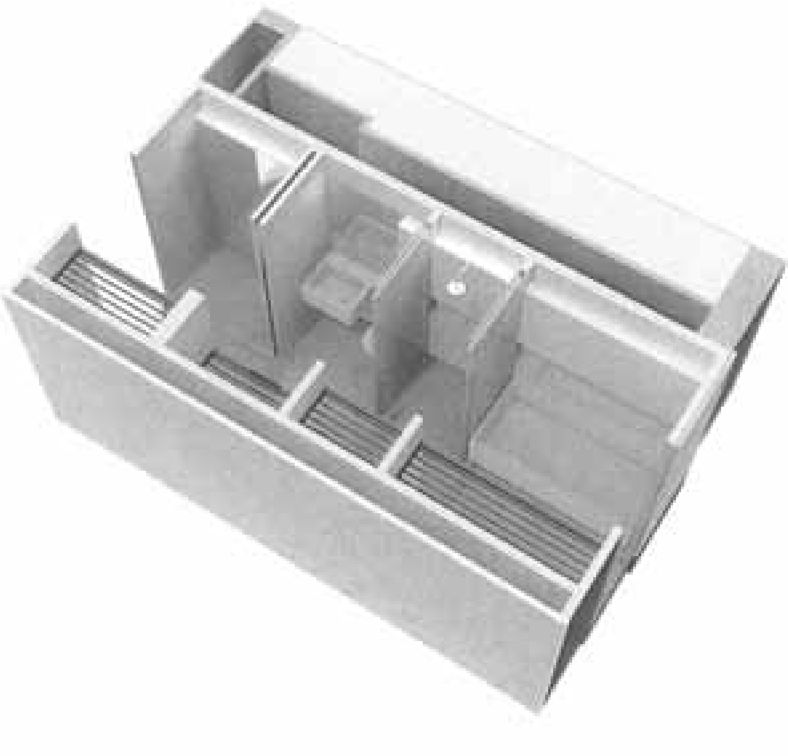
4. CONCRETE INDOORS



In this project we also want to exemplify the possibilities to use concrete in the living environment. Concrete is very formable and we believe it has a lot to offer when it comes to aesthetic qualities. For example all the sanitary areas have concrete surfaces instead of tile. It gives a nice and tidy surface without joints. It may contribute to less housework and an easier life.

5. SIMPLE AND SAFE

We have focused on assembling all the pipes, ducts and wires in a joint shaft. This shaft is the main supply for the house and connects the sanitary areas such as the bathroom and laundry room with the kitchen. There will be full access to the shaft via the kitchen area which renders the possibility to inspect the pipes and wires and to make modifications in the future. This is the core of the house and may be considered as a product of its own.



Poster Session

Thermal Actions on Concrete Structures due to Climatic Exposure

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Key Words: concrete, thermal actions, radiation, temperature, FEM,

1. INTRODUCTION

Thermal actions due to environmental influences lead to temperature changes in concrete structures. Temperature changes can be divided into an average temperature change and a linear as well as a non-linear temperature variation over the cross section. The average temperature variation is mostly due to variation in the annual temperature, while the linear and non-linear temperature variation is due to daily variation in radiation and wind.

The temperature variation in a concrete structure will lead to movements. If the movements are restrained, stresses are induced in the structure. These stresses may contribute to cracking in the structure. It is known from inspections of concrete bridges that cracks are more frequent on faces exposed to solar radiation. This is a clear indication that thermal actions have a significant influence on the performance.

The main objective with this project is to characterize and describe thermal actions due to climatic exposure. Methods shall be developed to determine design temperature profiles for a specific concrete bridge with given cross section based on climatic thermal actions using a FEM program and meteorological data from SMHI. The temperature profiles can be used to predict thermally induced stresses in both longitudinal and transversal directions of concrete structures.

2. RESEARCH SIGNIFICANCE

Cracking is a significant problem in concrete structures. To prevent and limit cracks the loads on a structure must be known. Thermal actions lead to temperature loads which can lead to cracking in the structure. It is important to develop methods to perform more detailed evaluation of thermally induced effects.

The use of such methods is motivated for large bridges with special design conditions, for assessment of existing bridges where thermal actions can be expected to contribute significantly and in connection with monitoring to distinguish thermally induced response from other effects.

3. METHOD

A concrete slab has been cast and mounted with thermo-couples to measure the temperature at various depths in the center of the slab. The measured temperatures are compared to temperatures calculated with a Finite Element analysis of the slab. In the FE model the different types of thermal factors must be estimated and included. To estimate the thermal factors (solar radiation, wind, ambient temperature and long-wave radiation) special measuring equipments have been installed at the site of the slab.

The verified FE model will be used to calculate temperatures in concrete structures with climate data acquired from SMHI over a period of approximately 40-50 years. From the calculated temperatures a statistical analysis will be executed to estimate extreme values for effective bridge temperatures and linear temperature differences.

4. RESULTS

In this stage of the project the measurements and modeling of the slab are the primary objectives. The results presented in Figure 1 are temperatures in the slab for a February day. Results from Finite Element calculations compared with the measurements will be presented in the poster at the symposium.

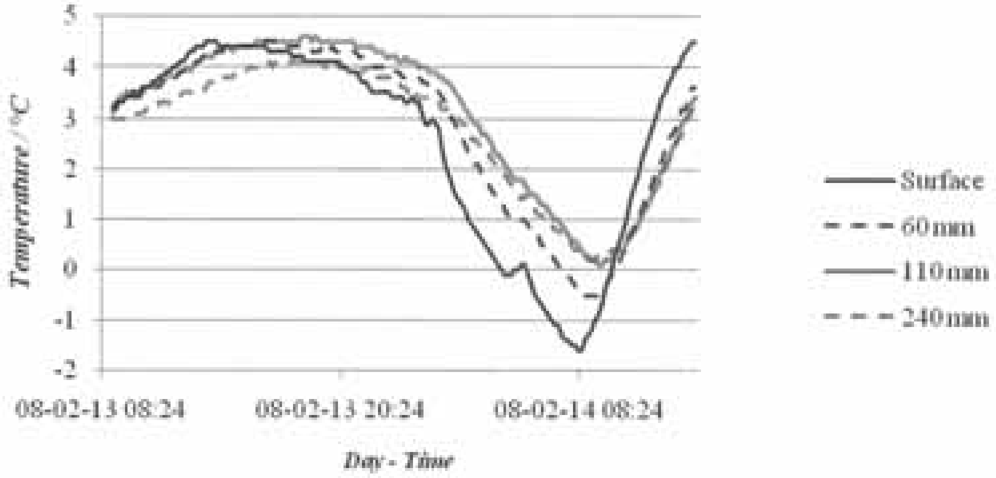


Figure 1–Diagram showing the temperature in the slab at different distances from the surface. Total thickness 250 mm.

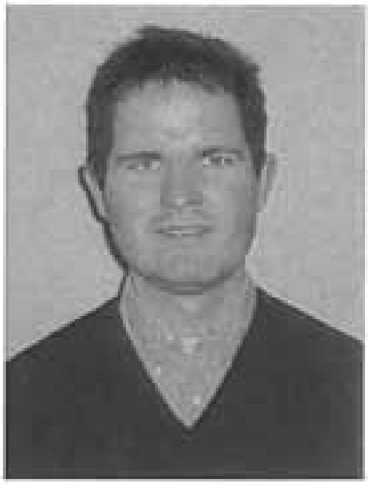
5. CONCLUSIONS

Figure 1 shows that the solar radiation affects the top of the slab more and makes it warmer than the lower parts. At night the opposite happens, long-wave radiation causes the temperature to drop in the top of the slab.

6. FINANCIAL SUPPORT AND PROJECT DATA

This project is a PhD-project of 5 years, started 2007, and is mainly financed by the Swedish Research Council Formas with additional support from the Swedish Road Administration.

Applications of Wireless Sensors in Concrete Structures



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Key words: Wireless sensor network, relative humidity, temperature, monitoring, maturity, moisture, embedment.

1. INTRODUCTION TO SENSOBYG

The Danish Ministry of Science, Technology and Innovation granted a R&D project to the building industry in Denmark in 2007. The project is titled "Sensor based surveillance in construction" or in short SensoByg. The project started in March 2007 and it will be running for 3 years until 2010 with a 4 M€ budget.

Danish Technological Institute is acting as overall project manager for the 12 industrial partners and 6 R&D performers. The latter includes Aalborg University (building physics), the Technical University of Denmark (wireless signals and radio wave technology), Alexandra Institute (software architecture for sensor networks), Lund University (moisture in building materials), Aarhus University (software systems and computer science) and Danish Technological Institute (sensor technology, concrete technology). The individual SensoByg members are described on the web site www.SesnsoByg.dk together with description of the work packages.

The main purpose of the project is to develop robust and reliable systems for monitoring buildings, civil structures and building materials by means of wireless embedded sensor technology. It is not the scope of the project to develop the sensor technology itself. Focus is placed on the systems handling the sensor data providing decision making tools for the building owners, the building operators and the contractors. One of the main challenges is to develop embedment techniques for the sensor unit so that it is able to survive the alkaline environment of concrete and installation techniques being robust enough to survive on the building site conditions. Installation techniques for newly cast concrete (in situ as well as precast) and post-installation in existing structures are included.

The activities within SensoByg are strongly associated with the monitoring of moisture (in terms of relative humidity) because moisture is almost always the driving force when damages on buildings and building materials are considered. Moisture governs the durability of concrete and it controls the risk of corrosion. Inside buildings moisture is associated with growth of fungi and degradation of organic building materials. Furthermore, excess moisture is responsible for health problems within houses. SensoByg is organised in 5 technical focus areas (Fig. 1, right) and 4 demonstration projects (Fig. 1, left). The focus areas are common R&D themes that apply to all the demonstration projects and applications. Three of the demonstration projects are closely associated with concrete:

- "Large structures" focus on civil structures such as bridges and tunnels. The scope is mainly to monitor the structures over several years or even decades in order to asses the need for rehabilitation without destructive condition surveys. One application is surveying of waterproof membranes on bridge decks but also splash zones and other hard-to-reach areas are included. Furthermore, wireless sensors are considered to monitor and to verify the concrete quality during casting and curing of new concrete structures.
- "Moisture in the construction phase" focuses on building structures such as walls and floors where moisture sensitive finishing is specified. Typically the moisture content in concrete floors is limited to say 85 % RH before the flooring is applied. Testing of concrete moisture content is cumbersome and often hindered by tight time schedules. Cast in sensors are expected to give the contractors better control and planning of the drying process during the casting and curing of concrete.
- "Concrete elements" focus on maturity and logistics of precast structural elements. This activity should help the manufacturer to improve his productivity and product quality from the casting bed to the final application.

Due to the limited space available it is not able to go into details with the specific topics.

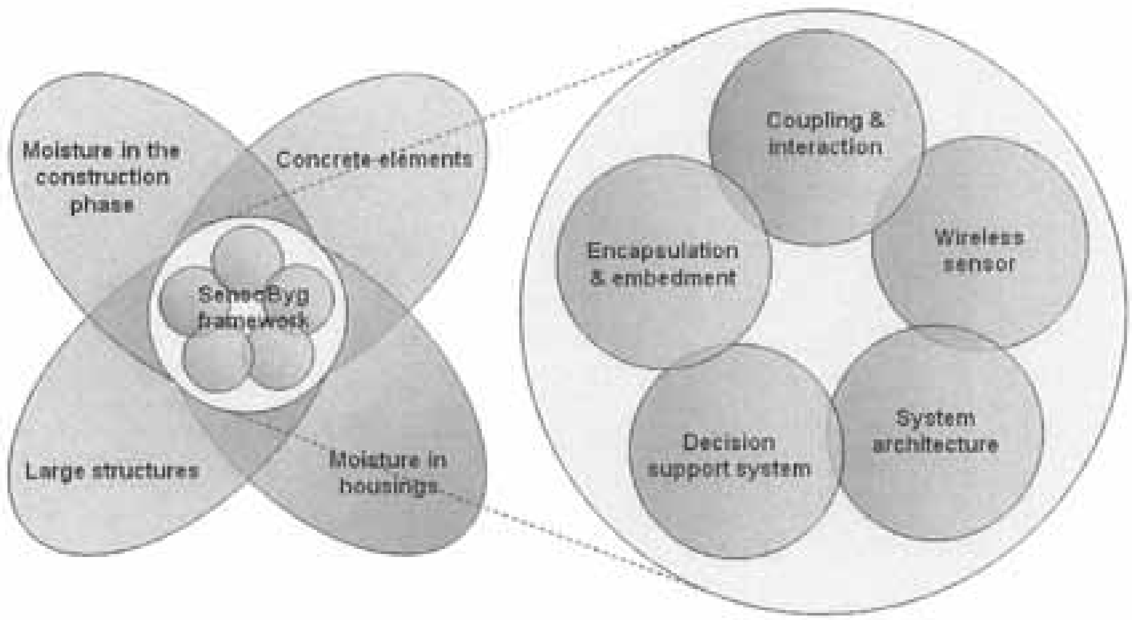
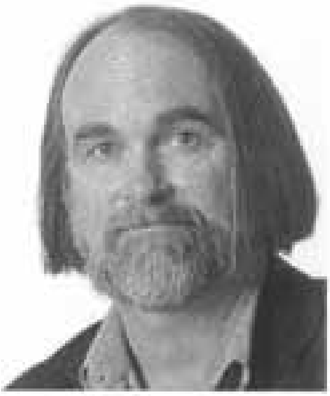


Figure 1 – SensoByg themes and activities.

Utilization of Cement Kilns for Environmentally Sound Management of Hazardous and Industrial Wastes in China



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Key words: Cement kiln, co-processing, hazardous, industrial, waste

1. INTRODUCTION

China faces great challenges with respect to sustainable energy and resource management, excessive pollution, environmental degradation and health effects, and with regards to environmentally sound and safe hazardous waste management.

The Chinese cement industry produced 1.065 billion ton cement in 2005, accounting for 808 kg per capita and approximately 50 % of the world production. The cement industry consumed about two billion tons of virgin raw materials, approximately 200 million tons of coal, around 100 million kWh of electricity and emitted more than one billion tons of carbon dioxide, millions of tons of dust and about 5 % of all SO_2 emissions in China. Ambient air levels of suspended particulates and SO_2 in Chinese cities are among the highest in the world and these heavy pollutant loads are closely associated with significant respiratory illnesses, estimated to cause 200,000 premature deaths each year in urban areas.

The Chinese State Environmental Protection Administration (SEPA) estimates that more than one billion tons of industrial wastes are generated annually, up to 30 million tons of hazardous wastes, approximately 150 million tons of municipal solid waste and more than 30 million tons of sewage sludge. The treatment capacity for these wastes is far from sufficient and there is an urgent need for improvement. The European cement industry is substituting up to 40 % of their fossil fuel consumption with waste materials and co-processing in the cement industry has been the sole solution for organic hazardous waste treatment in Norway the last twenty five years.

China has currently 6000 cement plants in operation but only a few plants have started to co-process waste as a fossil fuel substitute. Co-processing of waste in cement kilns offers advantages for the cement industry, for the industry producing wastes as well as for the authorities responsible for waste management. One of the advantages for authorities and communities is that this waste recovery method uses an already existing facility, eliminating the need to invest in a new, expensive and purpose-built incinerators.

2. PROJECT JUSTIFICATION

Cement kilns have proven to be effective means of recovering value from waste materials and co-processing in cement kilns is now an integral component in the spectrum of viable options for treating hazardous industrial wastes, mainly practiced in developed countries. A preheater cement kiln possess many inherent features which makes it ideal for hazardous waste treatment; high temperatures, long residence time, surplus oxygen during and after combustion, good turbulence and mixing conditions, thermal inertia, counter currently dry scrubbing of the exit gas by alkaline raw material (neutralizes all acid gases like hydrogen chloride), fixation of the traces of heavy metals in the clinker structure, no production of by-products such as slag, ashes or liquid residues from exit gas cleaning and complete recovery of energy and raw material components in the waste. One mega joule of waste energy will substitute one mega joule of fuel energy.

It is however necessary to have clear guidelines for co-processing of hazardous wastes in cement kilns, guidelines which also follow the requirements of the Stockholm and the Basel Conventions. To protect health and environment efficiently, it is necessary to learn from experience in other countries and to adapt the lessons learnt and best practice to the actual Chinese requirements and conditions. When such guidelines are in place the technology can be promoted in China through training and demonstration projects.

The purpose of the project is to establish the basis for large scale implementation of safe and environmentally sound treatment and recovery of hazardous and industrial wastes in the Chinese cement industry.

3. PROJECT ACTIVITIES

The project aims at integrating the best from international practice of co-processing waste materials in the cement industry with requirements of global conventions and Chinese conditions. The guidelines will be made operational and practical and will be tested and evaluated in pilot demonstration activities in selected Chinese provinces and cities. Based on the outcome of the demonstration activities, the guidelines will eventually be amended and improved and draft final guidelines will be issued. Capacity building and training will be cross cutting and overarching activities.

The following cities and provinces are candidates for demonstration activities: Beijing, Guangdong, Hubei, Shanghai, Shanxi, Sichuan and Zhejiang. To save time and money, the project will try to integrate and benefit from already on-going hazardous waste management activities, for example between international bilateral partners and Chinese authorities.

The project has been requested by the Chinese State Environmental Protection Administration (SEPA) and will be executed by their international unit, FECO (Foreign Economy Co-operation Office of SEPA), which will subcontract research to institutes, universities, Environmental Protection Bureaus in the various provinces etc. The project will be carried out in close cooperation with the industry, and will be managed and supervised by SINTEF. The project started January 2007 with a duration of 3 years.

Non-chloride Accelerating Admixtures for Concrete: An Overview and Current Norwegian Research

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Keywords: Concrete, admixtures, accelerators, setting, hardening.

1 INTRODUCTION

The rates of cement hydration reactions may be increased by adding small amounts of chemical substances, called accelerators, to the cement-water mix. Hence, an accelerator is added to concrete for the purpose of shortening setting time and/or increasing early strength development.

In the Norwegian COIN project (see Section 4) one goal is to develop efficient accelerators, especially for "slow hardening" blended cements. Accordingly, a state-of-the-art-report [1] has been written providing a historical and technical overview of accelerators, their mode of actions and the characteristics of today's commercial accelerators. This report is a short presentation of the COIN state-of-the-art-report.

2 RESEARCH SIGNIFICANCE

The introduction of blended cements has created a need for more efficient accelerators that have the capacity to speed up the hydration reactions and accelerate the hardening process. Calcium chloride is known to be an extremely efficient accelerator for both setting and hardening. Indeed, calcium chloride has been widely used for many decades due to its low cost/performance ratio. However, due to its tendency to promote corrosion of steel, it is no longer recommended for use in steel reinforced concrete. Accordingly, calcium chloride has been replaced by chloride-free alternatives, many being less efficient and characterized by high cost/performance ratios.

3 RESULTS AND CONCLUSIONS

Many chloride-free inorganic and organic salts and compounds have been reported to accelerate hydration of Portland cements. Typical inorganic compounds are alkali and alkali earth salts of nitrate, nitrite, thiocyanate, carbonate, sulphate, silicate and aluminate. Today, most commercial accelerators for normal concrete contain sodium and calcium salts of nitrate and thiocyanate, while sodium silicate and aluminium sulphate are used in shotcrete accelerators. Accelerating organic salts and compounds are found among carboxylic and hydroxycarboxylic acids and their salts, and alkanolamines. In the first group, calcium formate is a well known accelerator, while di- and triethanolamine are the most common among the alkanolamines. Alkanolamines are typically used as ingredients in accelerator blends, and rarely, if ever, as a sole ingredient. It is considered important that further R&D activities focus at:

Chemicals that speed up early hardening (not setting)
Today's most common setting accelerator based on technical grade calcium nitrate fulfils most requirements in the market concerning setting behaviour.
Technical grade bulk chemicals
The main chemical in a formulated admixture must be easily available at acceptable low cost.
Safety (chemicals friendly to humans and natural environment)
The "worst labelling" of a potential admixture for the future would probably be Xi, Irritant (Xn Harmul should be avoided).
Low alkali content
Attempts at developing alkali-free accelerators should be aimed at, especially if the accelerator is to be used at high dosages, as for shotcrete accelerators and antifreeze admixtures.
Synergistic effects of chemical blends
A lot of potential chemicals have been tested separately. However, future R&D efforts should focus on synergistic effects occurring when several chemicals are mixed.

4. PROJECT DATA AND FINANCIAL SUPPORT

COIN – Concrete Innovation Centre – is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology (NTNU) and industry partners work in the COIN projects (presently 5 projects). COIN involves moreover 15 - 20 PhD-students, 10 - 20 M.Sci-students and international guest researchers. The research covers a wide range of topics wherein *Advanced cementing materials and admixtures* is one of them.

COIN has presently a budget of NOK 200 million over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %). The present industrial partners are:
Aker Kværner Engineering and Technology, Borregaard LignoTech, Maxit Group, Norcem A.S, Norwegian Public Roads Administration, Rescon Mapei AS, Spenncon AS, Unicon AS and Veidekke ASA.

For more information, see www.sintef.no/coin

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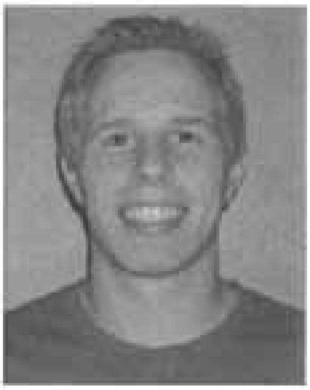
Method Development and Fundamental Understanding of Cement Chemistry



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Keywords: cement, vicat, ir, hydration

1. INTRODUCTION

The calcium silicate phases C_3S (alite) and C_2S (belite) ARE essential to the build-up of strength in Portland cement. They are formed above 800 °C, where C_3S is preferentially formed upon elevating the temperature, and increasing amount of added burned lime, CaO. The C_3S phase is responsible for short term strength development (days to months) while C_2S displays the better long term strength development (~years). The high energy input and the burning of calcite make cement production a major source of the green house gas CO_2 [1] that causes global warming. In recent years, the increased attention on environmental aspects of material conversion has influenced research towards possible modifications of Portland cement to better meet the increasing demands for sustainability in the construction sector.

2. RESEARCH SIGNIFICANCE

Our research concerns both method developments and fundamental understanding of the chemistry of cement. The influence of additives such as nanosilica and alkaline-free accelerators is studied to achieve fast setting and early strength even with a high belite/alite ratio to obtain more environmental friendly and sustainable cement. To fully understand the influence of additives on the hydration of cement it is important to study the early chemical processes. It is vital to know which chemical reactions that dominate during different stages to draw conclusions about e.g. the setting from a chemical point of view and to design additives that give desired properties. One major problem is to find techniques that are fast enough to monitor very short hydration times. This can successfully be solved by using a freeze drying method [2].

3. METHOD

The DR-FTIR-spectrometer used was a Nicolet Magna-IR 560 with an insert cell for diffuse reflectance spectroscopy. The measured range lies between 400 and 4000 cm^{-1}. The samples were hydrated for a pre-determined time and then frozen by immersion in liquid nitrogen and subsequently freeze-dried overnight. The Vicat apparatus was a Vicatronic automatic recording apparatus E040 and measurements were performed according to European standard EN196-3.

4. RESULTS

DR-FTIR combined with freeze-drying was used to monitor the chemical changes during hydration. Comparison with Vicat shows correlation between setting time and development of polymerized silica. Silica sol gives only a slight decrease in setting time. The alkali-free accelerator gives a significant reduction of setting time, and an even greater reduction in setting time is observed when it is combined with silica sol.

5. CONCLUSIONS

Application of a freeze drying technique has proved to be a well suited method to examine chemical changes during early hydration of Portland cement with DR-FTIR. The information from DR-FTIR can potentially be correlated with Vicat to determine the mechanism for setting in Portland cement.

6. FINANCIAL SUPPORT

The project is financial supported by Eka Chemicals AB and Post-Graduate School NMK, Natural Materials in Environmental Science and Cultural Conservation, Göteborg University and Chalmers University of Technology, Göteborg.

7. PROJECT DATA

Ph.D joint project with Eka Chemicals AB. The project started in April 2007 and is planned to be finished in April 2012.

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A New Reference Method for Analysis of SiO_2 in Silica Fume

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Keywords: analysis method, silica fume, standard test method.

BACKGROUND

"All" standards related to binder-materials in concrete use the same wet chemistry method to determine SiO2 content. A basic problem with this reference method is that the number of people who actually has sufficient experience to do it properly is rapidly dwindling. Another is that it is time-consuming and costly.

For these reasons, the facilities that offer the testing are disappearing, and judged by experience from some of the more exotic parts of the world, those that offer the service occasionally do not have the capability of performing the tests.

Today, the bulk of silica fume production is moving away from Europe and USA/Canada, and the anticipated capability of analysis laboratories is not increased.

Add to this that the method is really made for materials with a lower SiO_2 content – typically cements and the need of a new method is evident.

ACTION

Elkem, being the largest supplier of silica fume, with a global supply network with about 40 different facilities supplying through the company, has identified the need for a reference method that carries better precision in the determination of SiO_2 content than the wet chemistry method currently used.

"Everyone" today uses a XRF method with compressed powder tablets for determination of chemical composition of silica fume. However, it has been found that this procedure also is apt to be influenced by factors that will disturb the analysis result.

After a substantial amount of investigation, it has been suggested to apply a method that uses fused glass tablets as the reference method of the standard. The method has been developed in cooperation with leading members of the relevant ASTM committees, and is currently out for a ballot in ASTM C09.24 Supplementary Cementing Materials. The details will be presented in the public presentation.

As the dragnets searching for alternative materials are spread wider, the industry will appreciate a more stringent approach to the determination of chemical composition of supplementary cementing materials.

Unique Concrete Structures

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Key words: Construction automation, robot technology, concrete technology, digital architecture, formwork materials.

1. INTRODUCTION

The nature of conventional concrete production and technology has set up clear limitations to the aesthetic possibilities. The concrete architecture that we know today is often dominated by repetitiveness and recognisable geometries like squares and rectangles. Due to production methods still based on craftsmanship, spectacular concrete architecture is rarely seen, and almost only in connection with extraordinary buildings, where the construction costs have been excessively high. To lower the cost and to utilize the unused potential of concrete for unique structures, innovative development and usage of the construction industry is required.

2. RESEARCH SIGNIFICANCE

The aim of this project is to find solutions for mass customisation of concrete structures. This requires new ways to build unique formwork by the use of robots, and development of tailor-made concrete with special, engineered properties in the fresh state.

3. METHOD

The innovation of the project is the interdisciplinary approach with leading research and industrial partners bringing architecture, concrete technology and robot technology together.

The research in the project concerning architecture involves describing and visualising hypothesis of the needs and demands to the future concrete architecture and thereby a new architectonic idiom, characterised by the parametric design tools used.

The research concerning formwork focuses on analysing and optimising existing and new formwork systems. This involves analysing new formwork materials in relation to aspects like environment, economy, strength, flexibility and architectonic possibilities.

New and complex geometries give new challenges to the concrete in order to fill the form properly. This involves simulation of form filling with Self-Compacting Concrete using CFD (Computational Fluid Dynamics) technology in order to tailor the rheological properties of the SCC.

The main tool for manufacturing the formwork materials is a 6-axis robot. The potential of the robot regarding automation of i.e. the cutting, milling, melting and lifting processes will be exploited in the project. The research will focus on robots for single production, where the robot control unit automatically calculates the movement of the robot based on input from 3D CAD models.

4. RESULTS

The architectonic statement was finished in the first half of 2007. It concludes that the future will introduce a new amorphous digitally created architecture only possible to build with new industrial production methods. 3D CAD models where produced to visualise the architecture.

An extensive analysis of potential formwork materials has ended with a detailed list, which is the starting point for the test activities in laboratory. The list of potential formwork materials includes plywood, polystyrene, PU-foam, paraffin, latex, acryl, mould sand, clay and many more. Promising tests have been performed with robot milled expanded polystyrene placed in existing formwork systems.

5. CONCLUSIONS

The project has shown a big potential in using robots to mill out formwork materials in interesting geometries based on digital 3D CAD models. Together with existing formwork systems, the methods used in the project can make a complex digital architecture possible in the near future.

6. FINANCIAL SUPPORT

The project is financed by the participants in the project: Danish Technological Institute, University of Southern Denmark, School of architecture in Aarhus, Spæncom a/s, Unicon a/s, Giben Scandinavia a/s, Paschal Danmark a/s and MT Højgaard a/s. The project is financially supported by The Danish National Advanced Technology Foundation.

7. PROJECT DATA

Name: Unique Concrete Structures.
Duration: 3 years (2007-2009).
Project budget: € 1,7 million.

Accumulation of Entrained Air in Structural Concrete – A Case Study

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Key words: Entrained air content, admixture combinations, consistency.

1 INTRODUCTION

The use of concrete admixtures is nowadays a common way of producing high quality concrete with the desired properties in fresh and hardened state. As both the properties of fresh and hardened concrete are considered equally important, often more than one admixture is applied in the mixes. It is common knowledge that this can cause problems as concrete admixtures can interact with each other as well as with the hydrating cement components [1] and therefore can influence and even reduce each other's actions.

2 OBSERVED DAMAGES AND POSSIBLE CAUSES

Recently observed damages on several concrete structures were often due to high air contents combined with uneven distribution or accumulation of entrained air, resulting in structural elements with concrete of poor quality with low density and strength. These damages were not only observed on complex geometries where intensive compaction is required but also in comparatively uncomplicated structures such as concrete slabs, where no exceptional high compaction energy is applied.

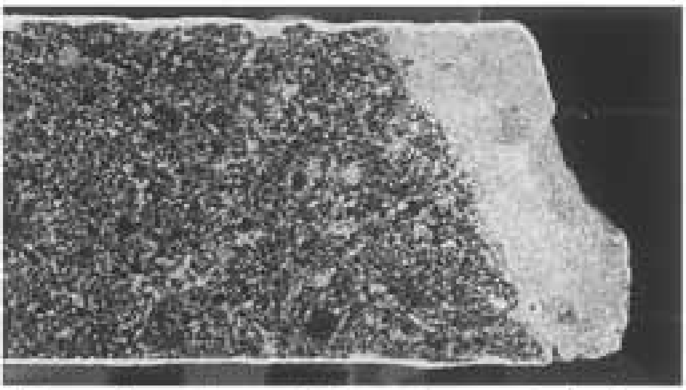

Figure 1 – Accumulation of entrained air at concrete surface.

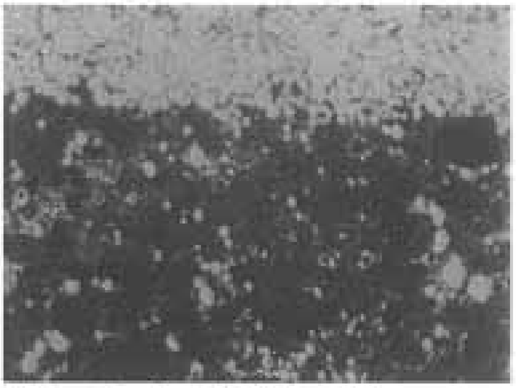

Figure 2 – Detail of Figure 1.

Possible causes for the above described damages can be the combinations of concrete admixtures (plasticizer, air-entraining admixtures, and retarding admixtures) as well as the construction method i.e. applied compaction energy or curing method.

3 INVESTIGATIONS

The concretes tested within this project were assigned to exposition class XD3/XF4 with a water-cement ratio of 0.4. The cement content and consequently the water content of the concrete mixes were relatively low, even though a high slump value was aimed for. Different combinations and amounts of concrete admixtures (plasticizer, air-entraining admixtures, and retarding admixtures) from different manufacturers were tested; and varying degrees of compaction by vibration were applied to determine influences from the construction method on concrete quality and possible accumulation of entrained air. Laboratory tests covered the examination of material properties of the fresh and hardened concrete (consistency, air content; compressive strength, density and air void analysis on hardened concrete).

4 RESULTS

It was found that the consistency of the fresh concrete is particularly important with regard to accumulation of entrained air. Generally concretes with lower slump values tend to have a lower air content which is evenly distributed, regardless of the brand of the admixtures or the higher need of compaction energy.

Concretes with the same content of entrained air but with higher slump values tended to segregation and foam formation (entrained air accumulation) during compaction. In some cases the foam formation could already be found in the concrete mixer. Retarding admixtures seem to have a negative effect with regard to the stability and the distribution of the entrained air in the concrete.

The causes for the effects described above could not yet be clearly identified and further investigations will be necessary.

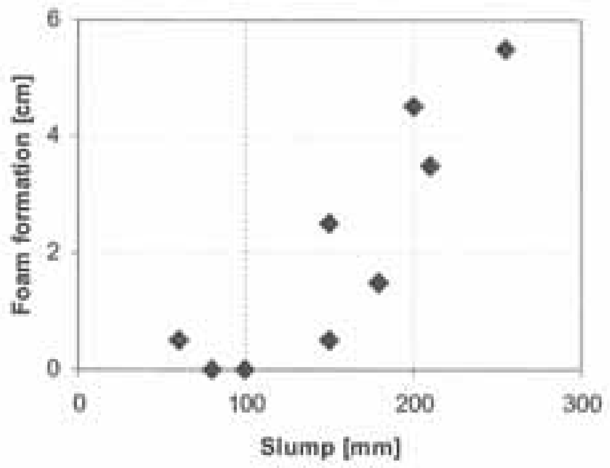

Figure 3 – Foam formation in relation to slump.

Within these investigations attention should also be paid to the effects of the cement content in the concrete mix and the content of fine materials (fine aggregate, fillers, etc.).

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Session J1 och J2
SVR-JSCE Joint Seminar – Future Perspectives towards the Development of Concrete Technologies

Standardization for Environmental Management of Concrete and Concrete Structures

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Key words: Concrete, environmental management, ISO, standardization.

1. INTRODUCTION

The environmental issue has now become a most crucial and serious problem for the continued existence of humankind. The earth's resources and energy have been consumed in great quantities by the rapid industrialization and population growth over a span of more than two hundred years since the industrial revolution, resulting in global environment changes that humankind have never experienced. Fortunately, the humankind has clearly recognized the nature of the problem, creating a concept of "sustainable development," which may be regarded as an environmental revolution. This concept means development that meets the needs of not only the present but also future generations while radically renouncing the conventional economic values--mass production, mass consumption, and mass disposal. In the 21st Century, incorporation of the concept of sustainability will be required for all social, economic, and cultural activities. Concrete is used in abundance for buildings and civil structures. Among the 10 billion ton annual concrete production worldwide, the cement production accounts for 2 billion tons (this amount is expected to be multiplied two to three times in the future). The cement production generates massive amounts of CO_2 generation. The massiveness of the quantity of resources used for concrete is understood in consideration of the fact that the world's current annual material flow is approximately 26 billion tons. The resulting massive stock is ultimately demolished, and the disposal of the huge amount of concrete lumps places a heavy burden on the environment.

Therefore, we need to find a way to reduce environmental burdens in concrete/construction sector. One direction is to develop an international system for coping with such circumstances. In this seminar, the existing ISO environmental standards and a new activity of ISO/TC71/SC8 for developing ISO environmental standards for concrete and concrete structures are described.

2. EXISTING ISO ENVIRONMENTAL STANDARDS

ISO has already published environmental standards, ISO 14000 series, which provide general rules related to methods of assessing environmental loads and the environmental declaration based on such assessment. Since these ISO standards primarily cover industrial products and services, ISO 15686-6 and ISO 21930 were developed to cover buildings, which have strong impacts on the environment. The former deals with the basic framework of the procedure for considering the environmental aspects of buildings, whereas the latter deals with that for issuing environmental declaration regarding building products. ISO 15686-6 and ISO 21930 standards can be regarded as a family of ISO 14000 series but with special attention to buildings.

3. ISO ENVIRONMENTAL STANDARDS FOR CONCRETE AND CONCRETE STRUCTURES

It is obvious that there are no other materials than concrete as the substitutes. Therefore, there is an urgent need to develop the system and technology for the reduction of environmental impacts of the concrete and construction sector. Based on the background, in the 14th ISO/TC71 Plenary Meeting in Brazil, ISO/TC71 agreed to establish a new subcommittee ISO/TC71/SC8 with the purpose to develop the standards on "Environmental Management for Concrete and Concrete Structures." The aim is to take the existing ISO framework environmental standards and provide concrete specific standards and information. The consistence with the existing ISO environmental standards, such as ISO 14000 family, ISO 15686-6 and ISO 21930 is thoroughly kept in the same way that the standards developed in ISO/TC71 aligned with those developed in ISO/TC59 and ISO/TC98. In other words, ISO/TC71/SC8 will develop the standards from the point of view on how the existing ISO environmental standards are specialized to concrete and concrete structures, how to consider the concrete-related environmental aspects in selection of raw materials, concrete production, execution, maintenance and demolition of concrete structures, reuse and recycling of concrete and also how to incorporate the environmental design into concrete industry.

Currently, the following standards are considered to be developed in ISO/TC71/SC8.

- ISO XXXXX: Environmental management for concrete and concrete structures
  - Part 1 – General principles for environmental considerations
  - Part 2 – Preparation of inventory unit data and system boundaries
  - Part 3 – Materials and concrete production
  - Part 4 – Execution of concrete structures
  - Part 5 – Maintenance of concrete structures
  - Part 6 – Demolition and reuse of concrete structures
  - Part 7 – Recycling of concrete
  - Part 8 – Environmental labels and declarations of concrete and concrete structures
  - Part 9 – Environmental design of concrete structures

4. CONCLUDING REMARKS

The world's cement production will reach 4 to 6 billion tons within the next few decades. It means that 3.5 to 5.2 billion tons of CO_2 will be generated in addition to CO_2 and other environmental impacts from construction activities. The G8 Hokkaido Toyako Summit will be held in Japan on July 7-9, 2008, in which the framework of global warming gases reduction approaches after the Kyoto Protocol will be discussed. It is predicted that at this meeting, numerical targets will be established for the reduction of CO_2. Concrete/construction sector will not be exempted from the obligation. Therefore, it is very important and urgent to reduce concrete/construction-related environmental impacts by developing appropriate standards under the existing framework of ISO Standards on the environment. The purpose of imitating work on the development of ISO standards for the concrete industry is the "the promotion of environment-conscious activities in concrete industry" and this is likely to lead to all industries. In order to initiate and accelerate sustainable development in the concrete/construction sector, there is an urgent need to imitate this effort on a global platform such as ISO/TC71/SC8.

Assessment of Structural Concrete – Results from a European Research Project on Sustainable Bridges

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Key words: Assesment, bridges, monitoring, testing.

1. BACKGROUND AND SCOPE

In order to ensure a sustainable society we need to take care of and use our exisiting concrete structures in the best possible way. This was the background to the initiation of a European research project on sustainable railway bridges.

The Project has developed improved methods for computing the safe load-carrying capacity of bridges and better engineering solutions that can be used in upgrading bridges that are found to be in need of attention. Other results will help to increase the remaining life of existing bridges by recommending strengthening, monitoring and repair systems, see [1] - [7]. A consortium, consisting of 32 partners drawn from railway bridge owners, consultants, contractors, research institutes and universities, has carried out the Project, which has a gross budget of more than 10 million Euros. The European Commission's 6th Framework Programme has provided substantial funding, with the balancing funding coming from the Project partners. Skanska Sverige AB has provided the overall co-ordination of the Project, whilst Luleå Technical University has undertaken the scientific leadership.

The overall goal of the Project was to facilitate the delivery of improved bridge capacity without compromising the safety and economy of the working railway.

The main objectives of the Project were to

- Increase the load-carrying capacity of existing bridges to permit axle loads of up to 33 tonnes for freight traffic at moderate speeds (say up to 100 km/hour).
- Increase the capacity for passenger traffic with low axle loads (up to about 17 tonnes) by permitting the maximum speeds to be increased up to 350 km/hour.
- Increase the residual lifetime of existing bridges by up to 25 %.
- Enhance strengthening and repair systems.

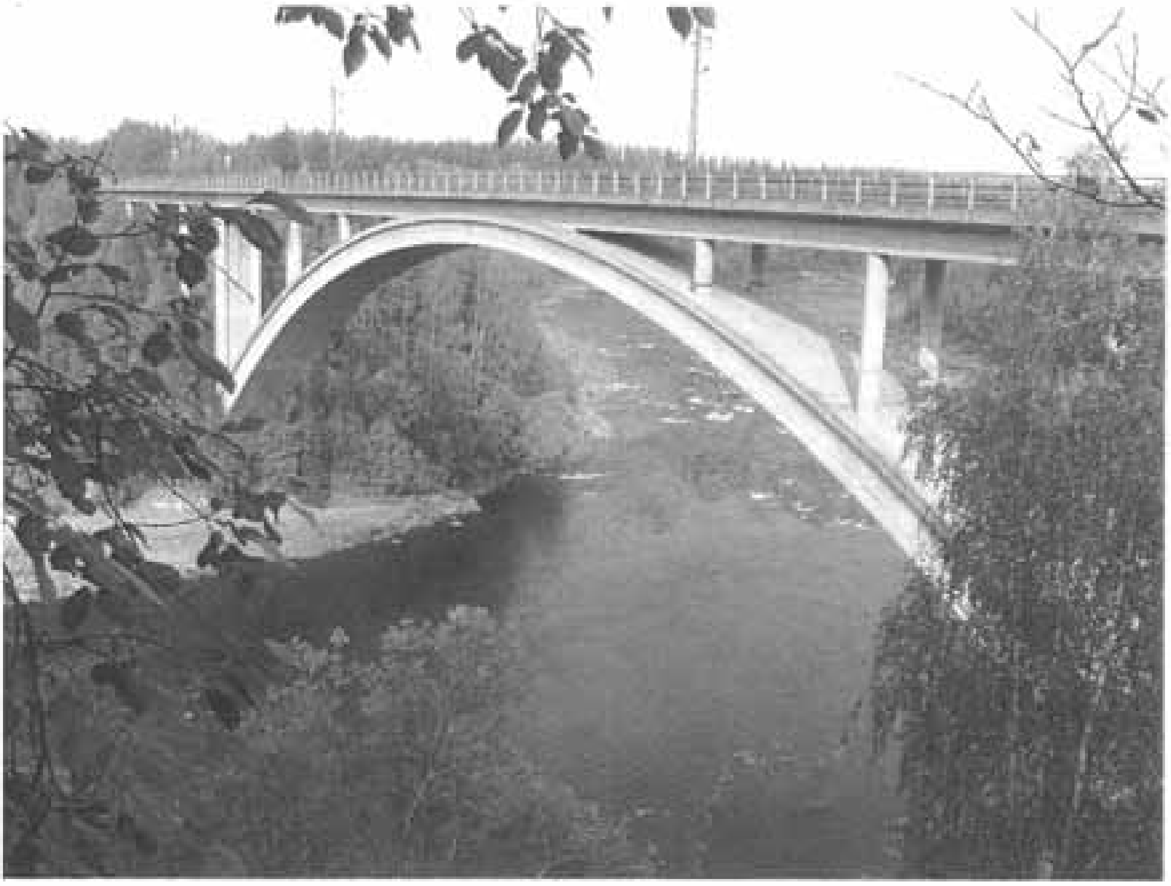

Figure 1 – In order to increase the allowable train axle loads from 22,5 to 25 kN the Vindel Bridge has been assessed with methods developed in the Sustainable Bridges project. The bridge is situated along the Swedish main northern railway line and crosses the Vindel River near Vindeln some 60 km NW of Umeå. It is a concrete arch bridge with a span of 110 m and a height of 22 m, which was constructed in 1952.

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Time-Dependent Structural Analysis for Life Simulation of Concrete Structures

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Key words: RBSN, truss networks, diffusion analysis, deterioration process, corrosion.

1. INTRODUCTION

Infrastructures in Japan are ageing, for example 50% road bridges become more than 50 years old in 2030's. The approach of the life cycle management that aims at making long-lived and lowering the maintenance cost of ageing infrastructures has been started. The quality of the management depends on long-term prediction technique of the structural performance and it can be discussed only after the prediction will be done in high accuracy. Therefore, the simulation method for long-term behaviour of concrete structures should be developed. In this seminar, a method to simulate the deterioration process induced by mass transfer is presented in which structural analysis and mass transfer analysis are combined [1].

2. TIME-DEPENDENT STRUCTURAL ANALYSIS CONSIDERING MASS TRANSFER

An important point to select the structural analysis method combining with mass transfer analysis is target scale. Mass transfer can be represented in various scales from micrometer scale of pore structures to millimeter of cracks. On the other hand, the structures also have several mechanical scales such as crack, specimen and member. In the analysis, the target scale is selected at crack which is important route of mass transfer and mechanical feature of concrete structures. Rigid-Body-Spring Networks (RBSN), which is one of discrete approaches, are used as structural analysis, since it is easy to deal with crack propagation of concrete directly. The method represents a continuum material as an assemblage of rigid particle elements interconnected by zero-size springs along their boundaries.

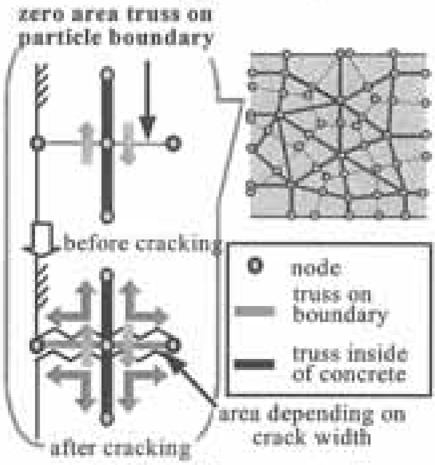
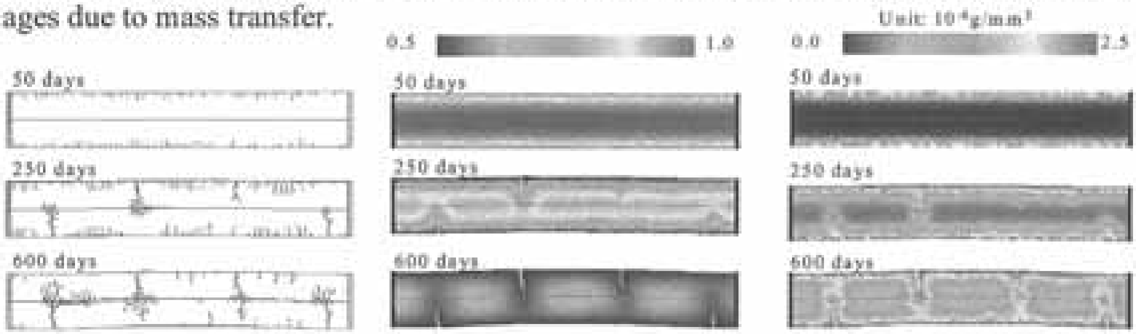


Figure 1 – Truss networks.

Mass transfer is continuous flow and it is usually analyzed by continuum model same as Finite Element approach, which is represented by partial differential equation. RBSN, however, does not require continuality condition. Therefore, truss networks model is used for mass transfer analysis to adjust the concept of structural analysis by using RBSN. Then, a simplified one dimensional diffusion equation using truss element is employed to carry out mass transfer. The truss networks set between rigid body nuclei and on boundaries as shown in Figure 1. The networks between rigid body nuclei represent the mass transfer within bulk concrete and the networks on boundaries represent mass transfer through crack. Therefore, the mass transfer through the crack can be considered in addition to through the bulk concrete, in which different diffusion coefficient from concrete material is assumed.

3. AN EXAMPLE OF ANALYTICAL RESULT CRACK PROPAGATION ANALYSIS DUE TO DRYING SHRINKAGE AND CORROSION

Reinforced concrete in which rebar of 1.0% is arranged at the center was simulated as an example to confirm the effectiveness of the developed method. The moisture transfer and the chloride ions penetration are considered in mass transfer analysis. Moreover, corrosion expansion of re-bar is considered by the compelling displacement when the concentration of chloride ion at the surface of rebar exceeds a threshold value. Figure 2 shows cracking behaviors, the distributions of relative humidity and the concentration of chloride ions at 50, 250 and 600 days obtained from the developed analysis method. At 50 days, many micro-cracks occurred at the specimen surface due to the effect of drying shrinkage. The soluble chloride ions gradually penetrated into the specimen via the boundary surface and the surface cracks. At 250 days, more shrinkage cracks occurred and major cracks reached the rebar, which led to diffusion of moisture and chloride ions through the cracks, causing the corrosion of the rebar. At 600 days, mass transfer through cracks accelerated because of the increase in crack widths. Moreover the cracks propagated along the rebar, since the specific concentration of chloride ions at the surface of rebar exceeded the threshold value. The analysis simulated well structural damages due to mass transfer.



(a)crack patterns (b)Relative humidity (c)Chloride ions

Figure 2 – Combined analysis of drying shrinkage and corrosion.

4. CONCLUSION

The simulation method for long-term behaviour of concrete structures becomes important, because the age is changing from construction to maintenance of infrastructures in Japan. In this study, an analytical method combined with structural analysis and mass transfer analysis was represented. Then, the deterioration process such as the cracking behavior under multi actions in consideration of drying shrinkage and rebar corrosion expansion were simulated considering the effect of mass transfer through cracks. The analysis was well simulated of the structural damages with deterioration process due to mass transfer.

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Applications and Recommendations of High Performance Fiber Reinforced Cement Composites with Multiple Fine Cracks (HPFRCC) in Japan

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Key words: Concrete, fiber, HPFRCC, multiple cracks, strain-hardening.

1. INTRODUCTION

High performance fiber reinforced cement composites with multiple fine cracks (HPFRCC) show remarkably high ductility under uniaxial tensile stress and excellent performance distinguished from conventional cement-based materials by multiple cracking and strain hardening behaviors. Characteristics of HPFRCC include crack width controlling capability keeping crack width in a permissible range. Appropriate use of the tensile performance can work out a structural component excellent in both durability and mechanical performance. The Japan Society of Civil Engineers (JSCE) has published the world's first design recommendations for HPFRCC [1]. English version of the recommendations is going to be published soon. In this seminar, applications of HPFRCC in Japan and the JSCE recommendations are introduced.

2. JSCE RECOMMENDATIONS FOR HPFRCC

Contents of the recommendations are shown in Table 1. The recommendations specify that structural performance, serviceability and resistance to the environmental actions have to be verified on the basis of performance verification concept. Test methods for measuring tensile strength, tensile strain capacity, and crack width are also specified because tensile performance is one of the most important material properties in the design of HPFRCC. The test methods enable us to define material properties regarding tensile yield strength, ultimate tensile strain capacity, and maximum crack width for given HPFRCC, which are subjected to the design verification. The recommendations allow cracks not only in ultimate limit state but also in service condition of members. The serviceability limit state design is required to verify the resistance to the environmental actions throughout the design life on the basis of the calculated tensile strain or crack width nucleated in members subjected to service conditions.

The recommendations are provided for synthetic short fiber reinforced cement composites that exhibit a pseudo strain-hardening behavior and form multiple fine cracks under uniaxial tensile loading. More specifically, the targeted materials are those that exhibit mean ultimate tensile strain capacity of more than 0.5 percent and mean crack width of less than 0.2 mm as determined with test methods specified in the recommendations. Applicable range of the

Table 1 – Contents of JSCE Recommendations for HPFRCC.

1 General
2 Design basis
3 Material properties for design
4 Load
5 Structural analysis
6 Safety verification of structures
7 Serviceability verification of structures
8 General structural details
9 Verification for resistance to environmental actions
10 Concrete work
11 Shotcrete
Testing and evaluation methods
Appendix

Figure 1 – Applications of HPFRCC.

recommendations includes steel reinforced HPFRCC members and existing reinforced concrete structures covered with HPFRCC layer, but excludes monolithic use of HPFRCC in members.

3. APPLICATIONS OF HPFRCC IN JAPAN

The following applications of HPFRCC in Japan take advantage of the superior mechanical properties and fine cracking mode of such composites.

- Bridge decks to improve fatigue resistance through the tensile force bearing capacity.
- Dampers in reinforced concrete buildings to increase energy absorption and suppress vibration during earthquakes.
- Surface repair of dams and irrigation channels (Figure 1) to improve shielding properties.
- Surface repair of retaining walls deteriorated due to alkali silica reaction to improve aesthetic appearance.
- Surface coating of railway viaducts for carbonation retardation.
- Surface coating of tunnel lining made with SFR shotcrete (Figure 1).

4. CONCLUDING REMARKES

Applications of HPFRCC are still in incunabula and associated with problems to be solved, while HPFRCC posseses a unique feature that has never been presented by the existing cement-based materials. Worldwide active research and development of HPFRCC imply a possibility to realize concrete structures with excellent safety, serviceability and durability performance.

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Innovative Strengthening Systems for Concrete Structures

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Key words: Strengthening, FRP, innovation, concrete, bonding, bridges.

1. INTRODUCTION

1.1 General

The use of concrete has been widely spread over the world as it is one of the most important construction materials, and a majority of our structures are built in reinforced concrete. A large amount of the existing structures were built just after the Second World War and are now reaching the end of their planned service life. In addition to this, increased loads, traffic flows, reuse and ongoing deterioration, often steel corrosion, even affect structures that are less than 20 years old. To replace the existing structure with a new one should in many situations solve the problems. However, this can very seldom be economically motivated. It is therefore important to develop new cost effective upgrading methods that can be used to prolong the service life and to increase the safety of the structure. Consequently, there is an increasing need to restore or strengthen civil engineering structures worldwide, in particular related to transportation because of ageing, deterioration, misuse of facilities, lack of regular maintenance and repair, use of inappropriate materials, construction techniques or both. Increased or changing loads may also lead to a need of strengthening. There exist several repair- and strengthening methods that are applied on existing concrete structures for this purpose, such as increase of the cross section of critical elements, span shortening with additional supports, external/internal post tensioning or fibre reinforced polymer composites. Externally bonded FRP (Fibre Reinforced Polymer) systems have been proven to be an effective strengthening method in repairing or strengthening structures. Since the end of the 1980s, the use of FRP is being researched and applied increasingly for the retrofitting of existing concrete structures. Typical applications are column wrapping, under seismic risk or for strengthening bridge piles. FRP composite materials have a number of advantages when compared to traditional construction materials such as steel, wood and concrete. FRPs offer excellent corrosion resistance to environmental agents as well as high tensile strength, light weight, and high modulus of elasticity. The use of FRP strengthening systems for rehabilitation of concrete structures has been considered successful. In this short paper two FRP strengthen systems partly invented and developed in Scandinavia will be presented. The systems are NSMR (Near Surface Mounted Reinforcement) and MBC (Mineral Based Composites).

2. FRP STRENGTHENING SYSTEMS

2.1 Near Surface Mounted Reinforcement (NSMR)

Bonding NSMR in the concrete cover in sawn up slots have now become a quite common strengthening method worldwide. However, the first known application was carried out in Sweden in 1997 and before then the systems were researched at Luleå University of Technology. In brief the strengthening is carried out by first sawing or cutting a groove in the concrete cover. The size of the groove depends on the dimensions of the NSMR bar and the thickness of the concrete cover. The groove is cleaned very carefully, first with pressurised water, then with compressed air. Adhesive is placed in the groove and the rod is mounted. The system may be prestressed or non-prestressed. The force transfer between the concrete and the rod is excellent and is superior to external surface bonded FRP strengthening, or the more traditional laminate or sheet systems used. In Figure 1 a photo of the strengthening for full scale test of a railway bridge is shown. The strengthening was carried out due to a need of increased flexural capacity – in the test, the shear failure was of primary interest. In this particular test an approximately 30 % strengthening effect was obtained.

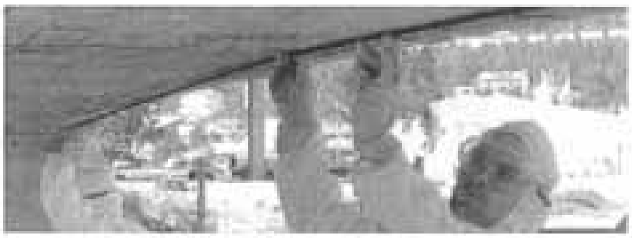

Figure 1 – NSMR strengthening of a railway bridge.

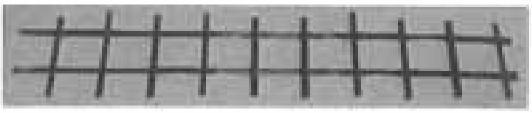

Figure 2 – Carbon fibre grid.

2.3 Mineral Based Composites (MBC)

Epoxy bonded systems exhibit some disadvantages, such as the diffusion closeness, poor thermal compatibility with base concrete, sensitive to moisture on the adherents at time for bonding, hazardous working environment for the manual worker and the problem of minimum temperature of assemble in cold climate regions. It is therefore of interest to replace the epoxy adhesive with a mineral based bonding agent, for example a polymer modified mortar, with similar properties to those of the base concrete applicable in a more environmentally friendly way. In a recently developed innovative strengthening system, the traditional epoxy bonding agent is being replaced by cementitious matrices to bond the FRP material to the concrete surface. The strengthening is relatively straight forward, first the concrete surface is sandblasted and a thin layer of polymer mortar is applied, either by hand lay-up or by spraying. In the wet mortar a carbon fibre grid is placed and another layer of mortar finish of the strengthening. In Figure 2 a typical carbon fibre grid used is presented. Tests, see [1] show that correspondingly strengthening effect as for FRP epoxy bonded systems can be obtained. The strengthen system has been applied in several field projects with promising result.

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Session A4
Aesthetics & Environment

The Visible Concrete Surface

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Key words: Aesthetics, concrete surfaces, visual ageing.

1. INTRODUCTION

Despite of the great aesthetic potential, concrete is rarely chosen as a visible construction material for its aesthetic qualities. Whilst physical durability has been investigated for years, aesthetic durability has been more or less overlooked. The project "The Visible Concrete Surface" has in the period 2005-2007 explored the potential of improving the aesthetic appearance of visible concrete in construction.

2. RESEARCH SIGNIFICANCE

The main research has involved exploring the architectural potential of concrete and the visual ageing of concrete. This has led to a number of tools intended for all parties involved in the building process.

The tools include reference projects to continuously gather knowledge from previous and future projects, check lists for each building phase, catalogue for determination of the visual uniformity of concrete facades, guides for predicting the ageing of concrete, etc. The developed tools are brought together with basic knowledge of visible concrete on the knowledge portal www.synligbeton.dk which was launched in October 2007.

3. METHOD

In order to achieve references showing the possibilities with concrete, a selection of good concrete architecture in Denmark has been made. These projects have been analyzed in three categories related to the concrete: Shape, Detail and Texture. Architectonic design has also been explored at the School of Architecture in Aarhus. Here students have created a number of interesting concrete units that exploit the big design possibilities with concrete. Also the interaction between architectonic design and texture of the concrete has been explored.

In order to predict how the weathering will effect the visual expression concrete surfaces, tests have been made on a climate machine developed at Aalborg Portland to accelerate the ageing.

4. RESULTS

The main result from the project is a dynamic knowledge portal called Synligbeton.dk that gathers the activities and experience from the project. The portal is devided into 3 categories:

4.1 Inspiration

Through works of architecture, architectonic experiments and number of different surface examples, the portal inspires to exploit the aesthetic potential of concrete. A part of the presented architecture is described detailed together with information about the concrete used.

4.2 Dialog

One of the big challenges in construction is to ensure a good dialog between the parties involved. To ease this dialog 4 check lists have been made for each building phase: sketching, planning, construction and maintenance. These check lists can be downloaded at the portal.

4.3 Tools

To this category several tools have been made. One of them is a guidance that deals with weathering of concrete. Another one is a catalogue for visual homogeneity, which is a tool to measure the visual homogeneity of a concrete facade.

5. CONCLUSIONS

The portal is a valuable tool for the parties involved in construction and a good starting point in the effort to accept concrete as an aesthetic construction material. The portal will be extended the following years.

6. FINANCIAL SUPPORT

The project is financed by the participants in the project: Danish Technological Institute, Aalborg Portland, Lundgaard og Tranberg, Aarhus School of Architecture, Betonelement-Foreningen, Dalton Betonelementer, Betonelement, MT Højgaard a/s and Bascon. The project is also granted financial support of 1.6 million DKK from the Realdania Foundation.

7. PROJECT DATA

Name: The visible concrete surface.
Duration: 3 years (2005-2007).

The Living Concrete Surface

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Key words: Concrete, surfaces, aesthetics, ageing, colour measurements.

1. INTRODUCTION

Concrete is publicly perceived as solid, an unchanging, maintenance-free entity. In reality concrete is constantly responding to its surroundings and ageing due to the same processes that affect natural rock; Erosion, soiling and growth alter the visual appearance of the surface, in addition to the normally recognized physical and chemical degradation mechanisms.

It is common knowledge to concrete practitioners that a concrete quality suitable for the environment to which it is subjected must be used, specified by the environmental class. Similarly, the surface quality should be selected according to the ageing environment, since in many cases the visual expression is of equal importance to the perception and maintenance cost of a building. In addition to concrete quality, shape, design and surface texture of a concrete structure significantly influence the ageing response to the environmental conditions. The present study focuses on the effect of different initial surface properties on aesthetic ageing rate.

2. METHOD

As part of a larger research effort, six different concrete surfaces with different initial properties have been subjected to accelerated aesthetic ageing in an instrument specifically designed for evaluation of concrete facades. The ageing rate was evaluated using colour measurements.
Concrete surfaces with different degree of residual cement skin covering and texture were investigated in comparison to a siloxane coated surface. Two different but very similar white cement based concrete recipes were used.

3. RESULTS

The result of the test is shown in Figure 1 -Hunter L is reflectance (100 % is pure white, 0 % is black). dHunter L is the change in Hunter L relative to initial value (before ageing), inverted.

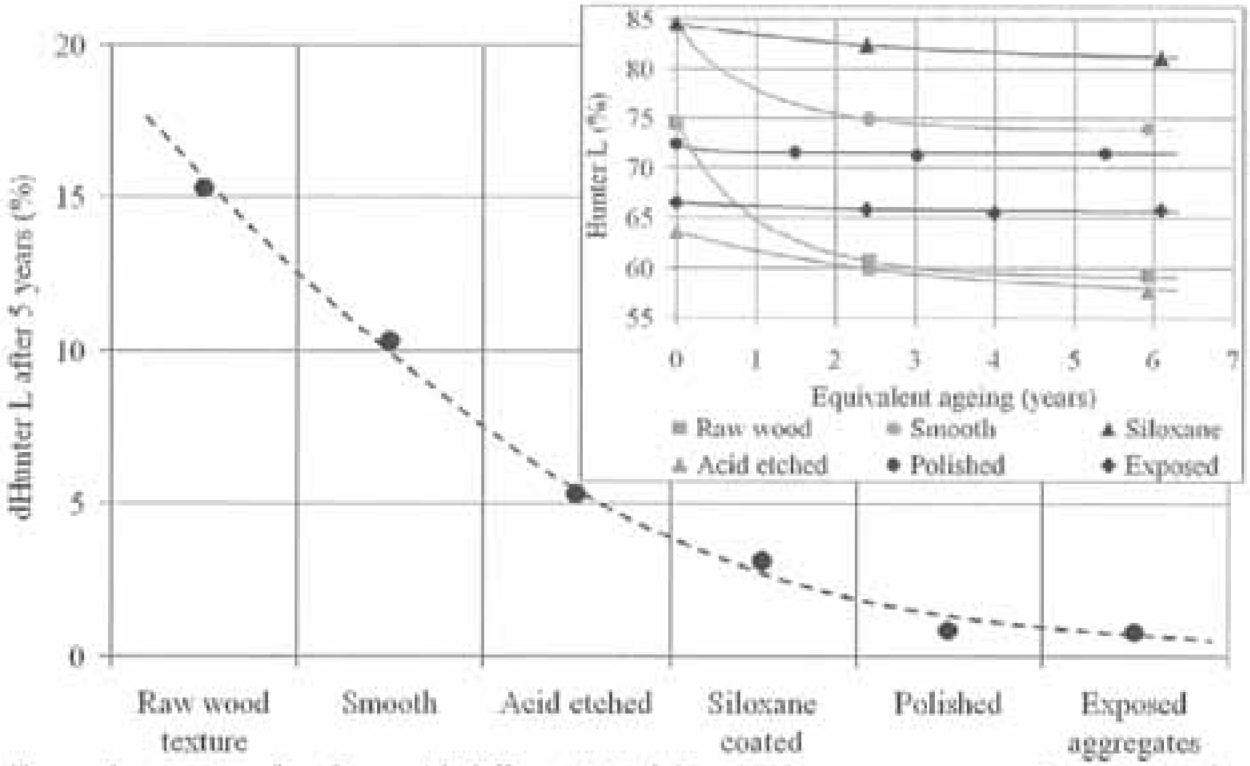

Figure 1 – Ageing of surfaces with different initial degree of cement paste covering compared to a siloxane coated surface. Colours (black or grey) indicate surfaces based on the same concrete composition.

The results clearly indicate a relation between surface ageing rate and initial cement skin covering: The more cement skin that initially covers the surface, the brighter it generally appears (with the exception of rough-textured surfaces), but the faster it also ages visibly. The weakened cement skin of the surface cast against raw wooden boards ages faster than the smooth surface, and the protected surface (siloxane coated) ages even slower, as one would expect. More results using the same method are available in [1,2].

4. CONCLUSIONS

Surfaces with the cement skin intact are generally brighter than acid etched or polished surfaces, but quickly age -the less visible paste on the surface, the less likely the surface is to age visibly. Parallel to the environmental classes traditionally used to select concrete quality, this should be used to select surfaces for building surface qualities suitable for providing the desired visual expression. Otherwise corrective actions like those used for inferior traditional physical quality may be required: Constant, cleaning, repairs and preventive maintenance.

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Concrete Surface Quality – An Overview

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Keywords: Surface quality, flaws, cracks, pores, efflorescence

1 INTRODUCTION

This literature study is a shortened version of a State of the art report written for COINs (Concrete Innovation Centre) surface quality project. COIN's main vision is "Attractive concrete surfaces". An overview of parameters which influence quality and aesthetical impression of the concrete surface has been made in connection to COIN's surface projects. The main focus has been on evenness of colour, occurrence of voids and pores and cracking due to drying shrinkage. Factors influencing the concrete surface such as material parameters, chemical admixtures, mix design, formwork, form releasing agents and production techniques are discussed. The characteristics of self compacting concrete are compared with ordinary vibrated concrete.

2 RESEARCH SIGNIFICANCE

The information gained from the literature study will determine further work within the projects.

3 RESULTS AND CONCLUSIONS

The appearance of the concrete will largely be determined by the formwork skin and the arrangement of the form and ties. Evenness of colour is for instance influenced by the homogeneity of the binder and the absorption properties of the mould.

Formwork can be grouped as absorbing and non-absorbing. Absorbing formwork materials like timber seem to absorb air bubbles near the surface and render good surface qualities. Non-absorbing formwork materials can result in extremely smooth and light coloured surfaces, but may have a greater tendency for producing air bubbles than absorbing surfaces.

Several types of form releasing agents exist in the market. These might be grouped in two groups, namely chemically reactive or barrier type. Chemically active release agents are most common for architectural concrete surfaces. It is not much published literature about the influence of form oil types on surface quality. Some reports do, moreover, not separate between barrier and reactive types of form releasing agents.

Form oils should be applied in accordance to the formwork material and in a thin layer. Excess form releaser might bead up against the fresh cement paste and increase the chances for staining and blowholes. Reactive form release agents might also retard the hydration of the cement close to the form. Retarded hydration might result in surface voids on the hardened concrete surface due to the formation of bleed water.

Efflorescence originating from lime precipitation can be avoided by use of cements with granulated blast furnace slag, fly ash or another pozzolanic material, use of tight formwork and protection of the concrete from transport of water or humidity which might wash lime out of the structure.

Cracking caused by drying shrinkage is influenced by water-cement ratio, cement type and fineness as well as admixtures and supplementary cementing materials which affect pore size distribution in the hardened paste. Type and amount of aggregates, drying and curing conditions and the type and shape of the specimen are also of importance. Conflicting results are reported for the influence of superplasticizers on drying shrinkage and effect of supplementary cementitious materials. These effects are possibly ruled by dosage and way of addition. Appropriate reinforcement and moist curing are well known countermeasures for drying shrinkage. Efforts have been made internationally to develop shrinkage compensating cements which contain expansive agents and shrinkage reducing admixtures which reduce the surface tension in the pore water.

SCC seems to be more sensitive than vibrated concrete with regard to surface finishing, due to the way it is cast, the nature of the formwork, the type and thickness of applied release agent, temperature of the formwork and weather conditions. However, SCC shows great potential to obtain good surfaces, in a way which is hard to get with vibrated concrete.

4 PROJECT DATA AND FINANCIAL SUPPORT

COIN - Concrete Innovation Centre - is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology (NTNU) and industry partners work in the COIN projects (presently 5 projects). COIN involves moreover 15 - 20 PhD-students, 10 - 20 M.Sci-students and international guest researchers. The research covers a wide range of topics wherein concrete surface quality and aesthetics is one of them.

COIN has a budget of NOK 200 millION over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and, NTNU (in all approx 15 %). The present COIN partners are the Research Council of Norway, SINTEF, NTNU, Norcem, Unicon, Maxit Group, Borregaard, Spenncon, Rescon Mapei, The Norwegian Public Roads Administration, Veidekke and Aker Kværner.
For more information, log on to www.sintef.no/coin

A European Assessment of the Environmental Benefits of Cement and Concrete

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Key words: CO_2, energy advantage of concrete, thermal mass, life cycle.

1. INTRODUCTION

The increased focus on the sustainability of construction materials and construction solutions provides an opportunity and a threat to the European cement and concrete industry. An opportunity to promote concrete as the sustainable construction material of choice – due to its inherent construction qualities e.g. durability, fire resistance and thermal performance. And a threat – due to perceived issues of high energy consumption, raw materials use and CO_2 production related to the cement making process.

A task force with representatives from the European Concrete Platform, a cooperation between the European cement and concrete organisations (CEMBUREAU, ERMCO, BIBM, EFCA, UEPG) is conducting a survey aimed at illustrating the benefits of thermal mass of concrete buildings in the context of Climate Change and enhance the contribution of concrete structures to a low carbon economy.

2. METHOD

A number of analyses have been carried out using different computer models to establish the effect of concrete on minimising energy consumption whilst stabilising the indoor climate [1,2]. The aim has been to investigate the energy balance in residential and office buildings in various European climates (from Sweden to Portugal), for both heavyweight and lightweight options. A simple, two-storey model building was designed for the calculations, being suitable for both residential and office use. Two different configurations were used: the heavyweight option included concrete floors, internal and external walls, whereas the lightweight option used typical timber or light steel frame components throughout except for a concrete ground floor slab. However, in both instances the thermal insulation used was identical, so that the influence of thermal mass could be examined accurately.

3. RESULTS

The results confirmed that concrete buildings can be more energy-efficient than lightweight structures. For residential buildings savings of 2-9% were found. The results were even more impressive for office buildings, where the thermal mass of concrete reduces the need for air conditioning. Savings of 7-15% were found.

Calculations of real buildings in UK/Ireland, Sweden, Germany and Portugal were used to validate these results. Good agreement with the theoretical building cases was found.

The results have been published in a brochure aimed at designers, specifiers, regulators and building owners and users [3].

4. ONGOING WORK

The thermal mass can be utilised further to produce low-energy houses, passive houses and zero-energy houses. This requires that concrete is used in an intelligent combination of heating, ventilation, solar shading, building structure and night cooling.

The task force is presently collecting a data base of best practise examples of the use of concrete to obtain houses with very low or no energy consumption and good thermal comfort. The aim is to provide a summary of the key design measures and issues that should be considered when exploiting thermal mass in residential and non-residential buildings. This will cover the following topics: building form, use of materials (concrete), building control, lighting/acoustics and project planning. These guidelines will be made available as inspiration for architects, producers and specifiers.

Use of concrete to save energy, CO_2 and natural resources in infrastructural works will also be examined. Best practise guidelines will also be set up to provide a summary of the key design measures and issues that should be considered to obtain the lowest possible CO_2 emission from construction, maintenance and use of infrastructural works. This shall take into account the full life cycle of the concrete structure.

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Environmental Characterisation of Concrete Products in View of the Ongoing European Standardisation Work

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Keywords: Concrete, environmental properties, leaching, standardisation.

1. INTRODUCTION

Leaching characterisation is the relevant way to evaluate the environmental properties of different materials. This is also well recognised in the ongoing development of the framework of criteria and methods in relation to the evaluation of the health, hygiene and environmental requirements for construction products mandated in M366 issued by the European Commission. The response from the European standardisation organisation (CEN) to the Commission mandate M366 is carried out in CEN/TC 351 [1]. In relation to the environmental issues for construction products, the ongoing Nordic project "General guidelines for environmental assessment related to CE-marking of construction products – test methods and regional requirements" was initiated in 2006 and will continue to the end of 2008 [2]. This project is financed by the Nordic Innovation Centre. The starting point in the Nordic project is the situation where testing is required and there may be a potential for a release to soil and water during the intended use of the product. The status of the Nordic project will be discussed in this paper.

2. RESEARCH SIGNIFICANCE

To ensure satisfying environmental properties of construction products when properly installed in the work, is an important and sometimes difficult task for the manufacture due to the complexity of the release scenario. For cement and concrete products, the release to soil, surface and ground water must be in an acceptable quantity and a variety of field parameters (e.g. rain fall, temperature, humidity, soil quality etc.) will influence the leaching rate. To ensure satisfying leaching properties for cement and concrete products is being increasingly important in the product development of new blended cements and new concrete mix designs were cement and aggregate are partly substituted by alternative materials (fly ash, slag, sludge etc.). In order to have a sound but realistic system for testing these leaching properties, standardisation is important in order to ensure the *level playing field* for construction products in Europe. However, field conditions are different from region to region and it is therefore decisive to identify the regional conditions (use of de-icing salts, freezing and thawing etc.) that will affect the leaching properties in the Nordic Countries. The findings of the Nordic project will therefore support the ongoing developments of horizontal test methods for leaching in CEN/TC 351.

3. RESULTS AND CONCLUSIONS

The project will cover the following:

- To evaluate appropriate CEN-test methods for the determination of release from construction products,
- to build up knowledge on testing results in relation to Nordic/European testing and scenario conditions,
- to give examples on how construction products used in regional areas can be classified according to relevant release scenarios,
- to develop an approach for interpretation of test results,
- to support CEN/TC 351 standardisation work with facts and knowledge on general and specific Nordic conditions and construction products.

Regional aspects need to be taken into account in assessment of environmental impacts and in development of national criteria (e.g. attention needs to be paid to sensitivity of the environment, exposure routes, e.g. surface water). Furthermore, there are only limited needs for development of special test procedures due to regional conditions. The following regional features may need to be considered and discussed:

- Freezing and thawing (e.g. resistance to weathering, water contact, influence of snow and ice),
- use of winter tyres that grinds/erodes the road surface (mechanical impact),
- atmospheric corrosion potential (e.g. presence of atmospheric pollutants or particulates),
- soil properties (e.g. high DOC, low buffer capacity, redox sensitive sulphuric soils),
- surface and groundwater properties (e.g. high DOC, salt content, low temperature and low buffer capacity),
- the use of de-icing agents (sodium/calcium chloride) on roads in winter maintenance,
- the properties of construction products (e.g. the use of special additives in cement, preservation agents, biocides, "material processability").

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A New Method for Field Testing of Emissions from Floor Structures

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1. INTRODUCTION

A new method for testing emissions from floor constructions called Passive Flux Sampling – PFS – is being developed at Cementa Research AB. The method aims at detecting emissions from alkali attack on adhesives and floor coverings in a simple and cost effective way and to create a reliable tool for field use in order to make it possible to verify the function of so called selfdrying levelling products. The same tool can also be used when there are suspicions of emissions in finished buildings.

2. METHOD

The passive flux sampler, PFS, is a cup with an inner diameter of 38 mm and an inner depth of 15 mm. The bottom of the cup is filled with Tenax that is covered with a mesh and a spring to hold the Tenax in place. When taking the sample from a surface, the cup is placeD upside down for a certain time, and the emissions coming from the surface are absorbed by the Tenax and can then be analyzed in conventional manner by GC-FID or GC-MS. In the laboratory where most of the tests in this project have been done, the application of the cup on the surface is done directly after the preparation of the cup.

In a field test, the prepared cup has to be transported to the site and back again after the sample has been taken. In order to avoid uptake of emissions during transport, a screw cap is put on the cup and then the cup is placed in an outer container, also with a screw cap. In this outer container Tenax is placed in the bottom to catch any emissions leaking in from the environment during transport.

In the first part of the project, measurements were done after taking up a circular hole in the flooring, as this is a technique that has been used before with the FLEC method. The emissions under the flooring are much higher than those coming through the flooring, and it is of course of great importance how long the time delay is between opening the hole and taking the sample of emission (the so called conditioning time). For various reasons, the method of measuring emissions under the flooring was abandoned in the project, and presently all measurements are done on top of the flooring.

3. RESULTS AND CONCLUSIONS

Table 1 shows a comparison between measuring under the flooring after different conditioning times and measuring on top of flooring. Two different products are compared.

Table 1. Emissions of 2-ethyl-1-hexanol, µg/m² ·hour.

Sampling	Selfdrying product	Normal drying product
Hole 10 minutes conditioning	820	810
Hole 4 hours conditioning	170	400
Hole 8 hours conditioning	60	440
Hole 24 hours conditioning	20	90
On top of flooring	**3**	**3**

The results show that the rate of decline of emission upon conditioning is quite different for the two products, in spite of the fact that the starting point is about the same and the emission on top of the flooring is also the same. These results are one of the reasons why the project went on with measuring only on top of the flooring.

In order to test the reproducibility of the method, a test series was carried out where 4 measurements in different positions on the same specimen on top of the flooring were carried out 4 days in a row, i.e totally 16 measurements. Specimen diameter was 380 mm.

Table 2. Emissions of 2-ethyl-1-hexanol, µg/m² · hour from a concrete specimen.

	Mean of 4 meas.	St. deviation		Mean of 4 meas.	St. deviation
Pos A	45	5.4	**Day 1**	55	14.9
Pos B	64	4.5	**Day 2**	59	9.3
Pos C	47	6.5	**Day 3**	55	13.8
Pos D	68	4.9	**Day 4**	56	11.7
Average	56	**5.3**	Average	56	**12.4**
St. dev.	**11,7**	0.9	St. dev	**1.9**	2.5

As can be seen from the results, the average standard deviation when measuring 4 times in the same position is less than half of what is obtained when measuring in different positions (5.3 vs. 12.4). Consequently the standard deviation of the over all average is much lower if you take the mean of 4 different positions each time as compared to when you take the mean of each position (1.9 vs. 11.7). The conclusion from these tests is that the reproducibility of the PFS method is good, and that the different emissions found in the different positions (A-D) on the same specimen are real, and not an indication of variations in the test method per se.

Comparing the absolute values of emissions in Table 1 and 2, one can see that the emission from the concrete sample is almost 20 times higher than from the samples with levelling compounds (56 vs 3 µg/m² . hour). This result is in line with other results in the project and also with earlier research in this field.

The conclusion is that the PFS method seems to be a reliable and simple tool for measuring emissions from floorings and can be used in practice to verify the function of selfdrying levelling compounds. Further validation of the method is going on.

4. FINANCIAL SUPPORT

The project is financed by Maxit Group AB. The laboratory work has been carried out by personnel at Cementa Research AB.

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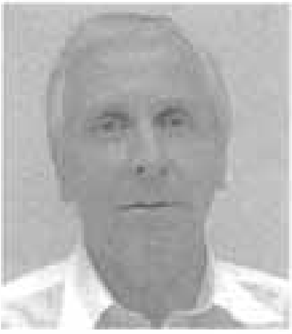
CO_2 Cycle in Cement and Concrete



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Key words: Cement, concrete, CO_2-emission, carbonation, LCI, LCA.

1. INTRODUCTION

1.1 General

The impact of CO_2 on the climate is of growing importance both technically and politically. At the production of cement clinker, limestone is heated and about 0,5 kg CO_2 is released per 1 kg of clinker. This is called calcination. At the production of concrete the clinker minerals will react with water and form cement hydrates. These minerals are not stable in contact with CO_2 (air) and moisture but will be transformed through what we call carbonation into stable calcium carbonate, which is the mineral constituting limestone. This means that there is a cycle. From a geological perspective all CO_2 released at the calcination will be taken up.

A recent Nordic introductory study show however that a substantial part is taken up already during normal lifetime (100 years) of concrete structures and most of it in a few years if used concrete is crushed and stored in contact with air.

1.2 Nordic study: CO_2 uptake during the concrete life cycle

The Nordic study was conducted 2003-2005 with funding from Nordic Innovation Centre and with participants from Denmark, Iceland, Norway and Sweden. The objective was to provide documentation of concrete carbonation during service life and secondary use. The project has been documented in five reports. Three reports cover background data and two reports include the results. See the reference list. One general result is that the study implies that about 20 % of the total (release from limestone and from fuel) amount of CO_2 emitted in the production of the Portland cement utilized in Nordic concrete construction will be reabsorbed in 100 years. It is however stated that the study is based on a number of assumptions and uncertainties and that there is a need for further work in the field.

2 PRESENT STUDY

The present study is concentrated to the Swedish market and can be divided into two subprojects:

2.1 Carbon dioxide uptake in concrete by carbonation

This subproject consists of four different tasks:

A. Models for and measurements of CO_2-uptake in cement based products.
B. CO_2-uptake after demolishing and crushing.
C. Investigation of the distribution of exposed concrete surfaces in the building stock.
D. Concrete with enhanced CO_2-uptake ability.

The task A is divided into several subtasks, for instance (1) state of the art, including a critical review of the Nordic Project, (2) development of a method to measure carbonation degree, (3) measurements on carbonation depth, carbonation degree and hydration degree and (4) models for correct description of the carbonation process.

The project is mainly conducted by CBI and LTH in cooperation. Task C is done by Cementa.

2.2 Climate gas strategies for cement containing products

This subproject is conducted by Swedish Environmental Research Institute – IVL. The objective is to, based on the results from subproject 2.1, analyze strategies and study technical, economical and legal aspects of the CO_2-cycle in cement and concrete and how it should be handled in reports, models and standards for life cycle environmental assessment of buildings. The reporting shall provide the cement and concrete industry with an enlarged decision basis for future CO_2-policy.

2.3 Project data

The project is financed by the Swedish Consortium for Financing Basic Research in the Concrete Field, by the Swedish Environmental Research Institute – IVL and by Cementa AB.

It started in November 2007 and will be finished at the end of 2009.

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Session A5
Production Technology

Recent Experiences with Self-Compacting Concrete in the Precast Concrete Industry

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Key words: self-compacting concrete, prefabricated elements, practical references

1. INTRODUCTION

1.1 General

The Consolis SAS Group is the largest manufacturer of precast concrete in Europe. It manufactures a wide range of prefabricated concrete products, such as floor slabs, beams, columns, walls and a large variety of complicated special elements. Consolis also makes products for infrastructure, such as pipes, railway sleepers and structures for bridges and tunnels and pavement blocks. The company has about 140 factories and operates in 21 countries. In 2007, Consolis had net sales of 1, 7 billion euros and employed of 10.000 employees.

Currently self-compacting concrete (SCC) is in regular use in most Consolis countries and its volumes are rapidly increasing. The annual use of SCC in 2007 exceeded 350 000 m^3 and made up about 35% of all concrete production in Consolis with flowable concrete (hollow- core slabs excluded). The list of products made with SCC is long: walls, beams, TT-slabs, columns, balconies, storage tanks, railway sleepers, bridge beams, sheet piles, cable culvert elements, safety barriers, septic tanks, manholes, even funeral coffins, and in addition, different kind of special elements.

The next step will be a factory designed only for SCC-use and it will look quite different from the current ones.

2. NEED FOR FUTURE DEVELOPMENT

2.1 Problems in present production

The production of SCC has increased significantly during the last years both globally and at Consolis Group factories. There have been many good experiences, but still some factories have difficulties to control workability and to achieve good concrete surfaces without porosity or cracks when SCC was used.

As well, some SCC-mixes are still too expensive due to the high amount of cement required. There may be several reasons: quality of materials, accuracy of equipment and methods for casting, finishing, and curing. Although there are manuals and guidelines that offer advice on producing proper SCC, it seems that factories will need even more precise recommendations to improve and keep constant the quality of SCC.

2.2 SCC plant in future

SCC is currently being produced using conventional production facilities and equipment. Only few real developments have been made in precasting production processes in considering the use of SCC. While this remains like this, part of the potential benefits of SCC can not completely be exploited.

One example about the future SCC-plant is to use a carrousel-type of production method. It means that the moulds are moving around the factory hall from fixed working place to another. For example, in the casting place the concrete can be floated directly from mixer to the mould under it. It means a much shorter period from mixing to casting and fast stiffening of SCC is now rather a benefit. The total production process can be studied and simulated by using a computer model. The use of this simulation model has proved that it is able to increase the production volume and effectiveness and reduce production cost 20-30%. The pay-back time for investments which are needed, will be 3-5 years.

3. CONCLUSIONS

We are now at the forefront of a new level of concrete technology. There are few matters which give so many technical, economical and environmental benefits. Probably all vibrated concrete will not be completely replaced, but SCC already is a dominant mode of manufacture.

There is still a lot of work to be done to optimise the SCC-mixes for each factory and each product. Also, production methods can be developed: maybe the concrete could be transported and cast by pumping or maybe the elements could be cured by using microwaves. There are several new possibilities!

We now have SCC – the old times will never be back!

Determination of Wear Resistance to Rolling Wheel of Screed Material with Floor Covering – A Round Robin Test

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1. INTRODUCTION

The European standard EN 13892-7 describes a test for determining the resistance to rolling wheel of screed material with floor covering. This property is very essential for the function of a screed material depending on where it is used. It is included in the so called P-marking system for levelling compounds in Sweden. The test method is optional in the harmonized standard EN 13813.

2. RESEARCH SIGNIFICANCE

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The rolling wheel test according to EN 13892-7 is based on an old Swedish standard and dates back long ago. On the material that is to be tested, a homogeneous PVC flooring is glued with a water based adhesive. This specimen is put into a rather advanced testing equipment where a swivel castor is running back and forth in two directions, totally 10 000 cycles. The load on the castor can be varied, and the result of the test is the load that three specimens can withstand without debonding of the flooring.

When the test was introduced in the European standardisation work, there was some doubt whether it is reproducible, since it involves many different steps from the specimen preparation to the actual loading and the final determination of if there is debonding after the loading. Also, since the equipment is rather advanced – it is not a commodity – equipments in different laboratories might perform differently. Against this background, it was felt important to establish the validity of the test by making a round robin test with laboratories from different countries taking part.

3. METHOD

A round robin test has been performed with 7 participating laboratories from 4 different countries. The test has been performed with one levelling compound from Maxit AB. In one part of the project all specimens were prepared by the Maxit laboratory and sent to the different laboratories for testing, in order to find out whether different test equipment gives different results. In another part of the project most of the laboratories produced their own specimens from material sent out by Maxit, whereby the influence of the whole test procedure is included.

In short, the material that is to be tested is applied on a concrete substrate. After an initial drying period, a 1,5 mm homogeneous PVC flooring is glued with a water based flooring adhesive. Then the rolling wheel test is carried out 28 days after casting the specimen. A steel wheel is loaded with a predetermined load (150, 250, 350, 450 or 550 N). The wheel travels back and forth in two perpendicular directions 10 000 cycles. This procedure takes about 8 hours. Then a drilling through the PVC flooring is done in six positions to determine if there has been any debonding caused by the loading. The result of the individual specimen is *pass* or *fail* for that particular load on the wheel. According to the standard three specimens have to pass in order for the material to fulfil the criteria for a particular load, designated RWFC followed by the load, e.g. RWFC 450.

For an unknown material, five specimens are needed to determine the RWFC value. The first specimen is tested with 350 N load and the next is tested on either 450 or 250 N depending on whether the 350 N test passed or failed. Likewise the following specimens are tested with a load that depends on the outcome of the preceeding test.

The results of the round robin test are encouraging. In the first part of the project all laboratories but one found results that were in good accordance. The results are shown in the Table 1.

Table 1 – Specimens made in the same laboratory.

Laboratory	Test 1	Test 2	Test 3	Test 4	Test 5	**RWFC**
1	350 P	450 P	550 P	550 P	550 P	**550**
2	350 P	450 P	450 P	550 P	550 P	**450**
3	350 P	450 P	550 P	550 P	550 P	**550**
4	350 P	450 P	550 ■	450 P	450 P	**450**
5	350 ■	450 P	550 ■	450 ■	350 ■	-
6	350 P	450 P	550 P	550 P	550 P	**550**
7	350 P	450 P	550 P	550 P	550 ■	**450**

P= Specimen passed the indicated load
■ = Specimen failed the indicated load

As can be seen from the table, all laboratories but number 5, found that the RWFC was either 450 or 550. From the statistical point of view, it is a question of chance whether the result is 450 or 550. Laboratory 2, e.g., made a mistake in test 3 when they did not raise the load to 550 N. Laboratory 5 had misunderstood the principle for the test and they also noted that the drill that was used to determine whether a specimen had debonded or not, was out of alignment. This could explain that they got failures at 350 N.

The results from the tests where the laboratories had produced the specimens themselves, showed similar results as in Table 1. All but one laboratory got RWFC 450 or 550. The one deviating (number 7) got RWFC 350. It could possibly be explained by the fact that it was found out that the load was 20 N higher than it should be.

4. CONCLUSIONS

The investigation shows that the standard EN 13892-7 is quite reliable and can give reproducible results in spite of the rather sophisticated specimen preparation and testing procedure involved.

5. REFERENCE

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Industrial Casting of Bridges with New Production Methods – The Importance of a Robust Self Compacting Concrete

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Key words: Cast in place concrete, industrialization, reinforcement, self compacting concrete.

1. INDUSTRIALISATION OF READY MIXED CAST CONCRETE

The implementation of SCC in addition to new reinforcement and form work techniques make it possible to increase the degree of industrialisation at construction sites markedly [1]. In a PhD research project full scale studies have been performed, "the Industrialized Concrete Bridges", and it was found that significant manpower reductions, improved working environment and higher quality of final result were facilitated by increasing the degree of industrialisation. The success was among other things dependent on how criteria of SCC were defined and how the concrete properties - and their variation - fulfilled the criteria.

2. FULL SCALE STUDIES

A key for the positive results of the full scale studies was that the owner, contractor, material supplier and designer cooperated during the complete project. Already during the design phase decisions were made in understanding between the partners that SCC and prefabricated reinforcement (e. g. carpet reinforcement) for the foundations and for some of the superstructure should be used and that so called Lean Construction principles should be utilized during both design and construction phases.

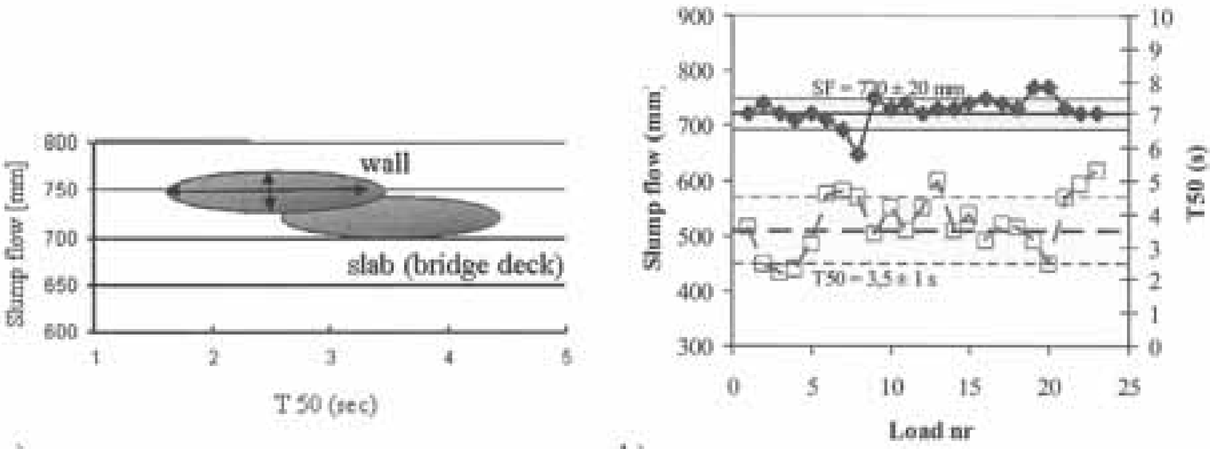
By using prefabricated reinforcement, the actual on-site production time at one of the bridges studied was reduced to 6 hours from a planned on site fixing time of traditional reinforcement of six days. Thus, the foundation could be cast on the afternoon the very same day i.e. at a time when the concrete plant normally has a low production engagement.

The average fixing time for carpet reinforcement in the bridge deck was 50 min/ton, which should be compared with at least 4 hours per ton for traditional net reinforcement. In total it was found that some 75 % of the on site assembling time for the superstructure reinforcement could be saved. The price for the material went up with roughly 50 % however, but since the cost for the assembling decreased by almost 90 % the overall economy was positively affected.

3. CRITERA FOR SCC AT AN INDUSTRIAL PROCESS - OPTIMIZATION

Using SCC saved approximately 65% of the casting time on one of the bridges as the number of workers involved was reduced. Crucial for the success of SCC is to define the performance of the product, which can, according to the Growth project Testing-SCC [2], [3] be discerned into three main parameters: 1) *Filling ability* 2) *Passing ability* and 3) *Segregation proneness*. For these parameters, criteria should be established to be met by a proper mix design depending on geometry of structure to be cast, reinforcement, form work type and, last but not least, method and local tradition on how to pour the concrete. Figure 1a shows possible target values and allowed variations of the *filling ability* (slump flow and T50) for horizontal and vertical bridge structures used at some occasions in Sweden. Example of result from SCC testing on site meeting the criteria is shown in Figure 1b. Criteria on *passing ability* and *segregation proneness* can, of course, be treated in a similar way.

The variation of SCC properties when delivered on site depends on a large number of factors such as fluctuations of properties of the concrete constituents, mixing procedure and transport conditions. In order to meet the criteria on site a robust concrete mix must be able to maintain its intended properties even though such parameters vary. To develop such a robust concrete mix is as important for a successful result as it is complex to accomplish. It is strongly believed that *both* theoretical analysis (by e. g. packing theories) *and* laboratory tests on cement paste, mortar and/or concrete are required in order to develop robust mixes.



a) b)

Figure 1 *a) Schematic workability diagram (slump flow vs T50) with examples of criteria for SCC for wall and slab, where the areas represent the tolerances.*
b) Slump flow and T50 at the bridge deck casting of the full scale test.

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Simulation of Construction Operations for the Erection of In-situ Cast Concrete Frameworks in Multifamily Buildings

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Key words: Simulation, in-situ cast concrete framework, construction activities, Extend^{TM}

1. INTRODUCTION

Traditional planning methods used in the building industry based on critical path methods do not fully consider the variability in construction activities or the availability of scarce resources needed by an activity at a specific point of time [1]. Simulation has been suggested as an alternative method to support decision making, planning and scheduling of construction processes [1]. This research aims at studying the process associated with the erection of in-situ cast concrete frameworks in multifamily buildings in order to identify possible improvements in terms of higher productivity, lower cost and higher resource utilization. The objective is to develop a model for simulation of different production strategies in order to identify ways to improve construction performance in terms of time and cost.

2. METHOD

In the research, simulation technique is used in order to analyze on site activities involved in the construction of in-situ concrete frameworks. A model for simulation of construction process has been developed based on knowledge derived from on site observations and data collection in four ongoing projects. The development process involved identifying construction activities (process mapping) and resource usage typically used in the construction of in-situ cast concrete frameworks. The model has been developed in Extend^{TM} which is a general-purpose simulation system [2]. The simulation model is based on a discrete-event approach [3] which is suitable for describing construction activities and involved resources [4].

The model has been validated in a project involving the construction of two six storey buildings. In order to demonstrate the use of the simulation model, alternative ways of allocating resources to activities were simulated. Two alternative resource strategies, P1 and P2, were simulated and compared to the strategy actually used (P0). Table 1 shows the activities included in the simulation together with the different strategies for resource allocation according to P0, P1 and P2. **P0** represents the construction strategy used in the observed project. The slab on each floor was poured as one single unit and each floor was divided into six wall cycles. **P1** represents a theoretic production strategy where additional resources were added to wall activities and the number of wall cycles per floor was reduced to four. In **P2,** further resources were added to some of the slab activities. **Bold** characters indicate a change in resource allocation compared to the reference, P0. Additional information required by the simulation model was total available resources during the framework erection, work load and unit time defined per activity and cost information for workers, material and equipment.

Table 1 – List of activities subjected to different setups of work crew allocation (P0, P1 and P2).

Activity/sub-process	P0/P1/P2	Crane	Activity/sub-process	P0/P1/P2	Crane
1. Formwork strip & cleaning	2A/**3A/3A**	X	13. Joint sealing and stop ends	1A+1B/1A+1B/1A+1B	-
2. Erect wall formwork (1st side)	2A/**3A/3A**	X	14. Install prefabricated columns	1D/1D/1D	X
3. Fix reinforcement	1B/**2B/2B**	x	15. Install stairs	2B/2B/2B	X
4. Install electric systems	1C/1C/1C	-	16. Install ventilation systems	1E/1E/1E	-
5. Erect wall formwork (2nd side)	2A/**3A/3A**	X	17. Install pipes	2F/2F/**3F**	-
6. Pour concrete walls	1B/**2B/2B**	X	18. Install electric systems	1C/1C/**2C**	-
7. Curing of concrete walls	-	-	19. Place top reinforcement	2B/2B/**3B**	x
8. Propping of floor slab	2A/2A/2A	x	20. Shuttering (shaft & staircase)	1A/1A/1A	x
9. Propping of balcony slabs	2A/2A/2A	x	21. Pour concrete slab floor	3B/3B/3B	*
10. Place lattice girder elements	2B/2B/2B	X	22. Curing of concrete slab floor	-	-
11. Install balcony slabs	2B/2B/2B	X	23. Props removal and reshore	1A/1A/1A	x
12. Place bottom reinforcement	2B/2B/**3B**	x			

A= Carpenters, B=Concreters, C=Electrician, D=Sub-contractor (steel), E=Ventilation contractor, F=Plumber, X=Crane used during whole activity, x=Crane used partially during activity, *=concrete pump

3. RESULTS

The simulation experiments show that P1 result in a 3.6% shorter construction time and 6.5% higher construction cost compared to P0. P2 results in a 14% reduction of total construction time but a 6.8% increase of construction cost compared to P0.

4. CONCLUSIONS

Simulation could be a complement to traditional planning methods enabling to consider the availability of resources but also the uncertainty and stochastic characteristics of a construction project. The simulation could support site managers in the decision of suitable method based on project specific objectives and prevailing conditions. Simulation of alternative construction methods and the influence of external disturbances on construction performance are examples of interesting areas for further research.

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SCC Towards Improved Construction Technology

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Key words: Self Compacting Concrete (SCC), formwork, design methods, vertical formwork, construction technology.

1. INTRODUCTION

The contractors in Sweden were among the first to use SCC. Despite this fact, the share of SCC in on-site casting is today only 5-10 %. The share in the precast industry is substantially higher. A few known factors may explain the low share. One of these known factors affecting the use of SCC is the formwork technique. The technique developed for conventional, vibrated concrete is not optimal for SCC. The special attributes of SCC, e.g. fast concrete filling, bottom to top form filling, casting against an overhead form, are not considered. The formwork design is highly dependent on form pressure and the movement of concrete in the formwork.

2. RESEARCH SIGNIFICANCE

Concrete construction and reinforcing works have traditionally been laborious and time consuming. Self Compacting Concrete (SCC) now offers an improved working environment and increased degree of mechanisation. This ongoing research project aims at investigating, analysing, and further developing the technology for SCC in civil engineering construction.

3. METHOD

The research method consists of the following elements:
(1) An inventory and investigation of international design methods for vertical formwork through interviews and literature search.
(2) An investigation of existing Swedish and international methods for formworks and SCC castings through site visits and an interview survey.
(3) Identification of future construction technology for SCC.
(4) Development of a proposal about new or improved design method for SCC and conventional concrete formwork.
(5) Proposal about new or improved formwork and construction technology.

4. RESULTS

The main objective of the research project is to substantially improve the working environment and the construction technology in civil engineering by increasing the share of SCC. The advantages of SCC - excellent material properties and optimized casting - enable the share of SCC to reach much higher levels. During the first parts of the project, one can expect to see clear and distinct proofs of the shortcoming in current formwork technology (including formwork design) and casting technique.

The first element of the research project, an inventory and investigation of international design methods for vertical formwork, resulted in a research paper [1]. One important conclusion in the paper is that current versions of codes for design of formwork for concrete have to be adjusted for SCC in order to enable this technique to be fully utilized. Presently, they are only covering conventional concrete. A comparison between five international codes shows both similarities and differences. It is possible to find practical examples for which the formwork pressure is very similar, but the differences increase if the parameter values deviate from the most common casting situations. For high casting rates and high slump values most codes approach hydraulic pressure. This might, however, be too conservative for SCC since measurements show pressure values substantially lower. Consequently, the existing codes cannot simply be extrapolated to SCC. Some general research areas are suggested: SCC robustness, accuracy of scales, mixing process, transportation and test methods for thixotropy at site. In the laboratory, tools for characterisation of SCC properties have been developed and a more complete study of parameters (constituents, temperature etc.) has to be conducted to enable the development of reliable design methods for vertical formwork. Yet another research area is the development of formwork systems. It is possible to instrument the formwork with pressure sensors or load cells in order to monitor the pressure development on-line as input for casting rate control. Other crucial parameters are form characteristics, reinforcement configuration and how vibrations from machines at the site will influence the thixotropic structure at rest.

5. FINANCIAL SUPPORT

Financial support from the Swedish Road Administration is gratefully acknowledged.

6. PROJECT DATA

Ph.D. project with starting time 2006 and anticipated final day during 2009.

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Mapping of the Concreting Production Process

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1. INTRODUCTION

In December 2006, the INDUCO project was launched, with the purpose of developing technologies for monitoring and controlling concrete production. A prerequisite for developing and implementing these technologies is a thorough analysis and mapping of the concreting process. This will help us to identify the needs and potential usefulness of new technology and facilitate a quick assimilation once it becomes available. We have been working together with the industry in making an accurate description of the concreting process and identifying which properties that needs to be followed. This mapping covers the process from the assembling of raw materials until 28 days after mixing. It also incorporates a mapping of the prefabrication concreting process. Interviews, workshops and visits form the foundation for our mapping. We have chosen to use the functional modeling language IDEF0 in producing the process charts. Future work aim towards improved control and efficiency of the processes.

2. RESEARCH SIGNIFICANCE

Working towards a mapping and subsequent understanding of the process of concrete production will generate substantial benefits. We will identify the needs of the industry, as well as potential uses for new technology. We will also identify new potential markets for the concrete manufacturer, with the possibility of taking on new tasks and responsibilities. Lastly, a thorough mapping of the various processes will identify possibilities for improved efficiency of the various sub processes.

3. METHOD

Workshops, interviews and study visits form the foundation of this work. The author has chosen to work with the functional modeling language IDEF0 in producing process charts. Initial charts form the basis for discussions at workshops, where they are improved upon and where ideas for improvements in the processes are aired. This facilitates in choosing areas to focus on in later pilot projects within the INDUCO project.

4. RESULTS

Working towards an accurate description of the concrete production process has helped in identifying the needs of the industry. It has yielded an understanding of how the various sub processes are connected and their significance for the main process of concrete manufacturing. The end result is suggested areas for improvement and applications for new technology such as isothermal calorimetry and wireless sensors. Isothermal calorimetry may be used for monitoring property development in concrete. It could also find potential use as control of cement quality at delivery, indicating variations in different batches. Potential uses of new technology will be tested through pilot projects within INDUCO.

5. FINANCIAL SUPPORT

This project is funded by Vinnova, Cementa AB, Sydsten and Lund University.

6. PROJECT DATA

The work of mapping the concrete production processes has generated ideas for areas of improvement. The suggestions form the basis for pre studies, which will be performed during spring of 2008. Some of these studies will be chosen for pilot testing, to be performed in the fall of 2008. At lease one of these pilot tests will concern new test methods.

Industrialized Construction with SCC Obtaining Important Benefits

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Key words: SCC, benefits, economy, productivity, working environment, robustness.

1. INTRODUCTION

Self-compacting concrete (SCC) is an important possibility for the industrialization of construction as it can, if managed properly, decrease the number of workers needed during casting and become economically profitable as well. Experience has shown that SCC not alone automatically gives a clear improvement of productivity. Therefore, within this research project, feasibility studies were carried out to grade various measures for industrialization of bridge construction. Thus, ten already constructed concrete bridges were followed up regarding unit times and costs for reinforcement, formwork and concrete and it was identified where major advancements in production can be achieved, Figure 1. A large man power reduction was achieved with a more effective handling of reinforcement – a well known circumstance. Different solutions for effective reinforcement fixing can thus be applied at various parts of bridges and as large as 80% of the reinforcement fixing time at the production site can be saved. Also if the formwork can be designed to be permanent on the construction, savings of 10 -15% on working hours can be achieved. SCC comprises many advantages compared with traditional concrete (i.e. faster casting, better working environment, productivity enhancement etc) that can result in a decrease of man hours with up to 75%, Figure 1.

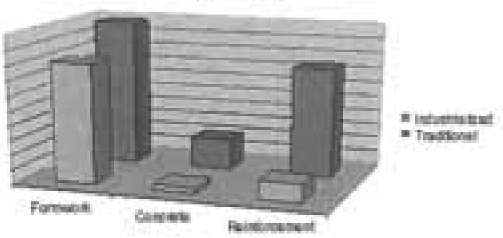

Figure 1 – Possible reduction of man power requirements if industrial methods are applied to concrete bridge construction.

2. INDUSTRIALIZATION

Industrialization is often mentioned as the measure to be taken and its definition is often debated in recent literature. It is thus stated that, to reach an industrial process, focus cannot only be on the production apparatus. The whole process from project idea to completed project needs to be controlled. Other important issues that must be addressed in an industrialised process are logistics, collaboration between partners, standardized solutions and design concepts, pre-manufactured highly processed components and information technology as well as Lean Construction philosophies.

2.1 Lean Construction

An important component of industrialization is to change the organisation at the site and the attitude of the personnel. Philosophies of Lean Construction can thus be a useful tool. In Lean Construction waste (in Japanese: *muda*) plays a central role, whose definition is any human activity that absorbs resources without creating any value [1].

2.2 Industrialization in production and the working environment

According to a study at the Danish Technological University [2] some 26 % of a worker's average day consists of concrete casting and reinforcement fixing (approximately 10 % and 16 % respectively). This work is often done in awkward postures with heavy equipment such as the poker vibrators for the traditional concrete or with heavy material when placing the reinforcement piece by piece. Probably the largest benefit with using SCC and prefabricated reinforcement is, as mentioned earlier, the improvement in working environment. By using a program called ErgoSAM a comparison between different working methods can be performed. This model observes the risk of acquiring Work-related Muscular Skeletal Disorders (WMSDs) on combinations of the variables; work posture, force and repetition.

3. FULL SCALE PROJECTS

Two full scale projects have been studied with the concern of SCC and reinforcement. The first full scale project comprised SCC and "new" reinforcement solutions such as reinforcement cages for the foundations and rebar carpets for the superstructure. In total, the bridge consisted of approximately 280 m^3 SCC cast at four occasions. To facilitate the introduction of the new working methods, the design and production planning of the bridge were carried out according to Lean Construction philosophy [3]. The second project consisted of two identical bridges next to each other. At these bridges the focus was on the implementation of SCC. The total amount of SCC for both bridges was approximately 550 m^3.

4. CONCLUSIONS

The largest economic benefit from introducing SCC to a contractor in civil engineering projects is probably on the superstructure. This since the largest number of workers is needed during casting of traditional vibrated concrete for the structure and therefore is associated with large casting costs. The number of workers needed can be markedly reduced if SCC is introduced and proper planning has been carried out before casting.

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Session A6
Admixtures & Aggregates

Concrete with Low Permeability

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Key words: Admixture, concrete, hydrophobicity, permeability.

1. INTRODUCTION

Concrete with low porosity/permeability is one of the activities within project 1 "Advanced cementing materials and admixtures" in the Norwegian centre for research driven innovation COIN (Concrete Innovation). The objective is to make concrete with low porosity and permeability, but focused on matrix.

Two state-of-the-art reports (STARs) were scheduled for 2007 on different approaches to achieve the objective; 1) "Low porosity through particle packing" dealing with obvious systems like adding fine particles (e.g. silica fume) to more advanced systems focusing on avoidance of initial ettringite formation functioning as spacers hampering packing of cement grains in the fresh state and 2) "Low permeability through hydrophobicity" dealing with hydrophobizing agents intermixed in the concrete and not applied on the surface of hardened concrete. However, only the second report is finalized at present and reviewed in the next section.

2. LOW PERMEABILITY THROUGH HYDROPHICITY

The durability and aesthetic appearance of concrete may be improved by the addition of hydrophobizing agents as a consequence of reduced water permeability.

Hydrophobizing agents lead to less water absorption at the same time as they let water vapour out. This may lead to a dryer interior over time and thereby reduced rate of detrimental reactions needing liquid water as reaction medium. The ingress of water born aggressives like chlorides will be reduced (in particular in marine splash zones), but also corrosion rates may be decreased. Carbonation rates may, however, be somewhat increased.

Vegetable oils seem to be the most cost-effective hydrophobizing agents as good effects may be achieved by additions of only 0.5 % of the cement mass. Furthermore, the cheapest and most available vegetable oil based on rapeseed is among the most effective tested as examplified by capillary suction in Fig. 1 [1, 2].
It is recommended to continue research on the effect of rapeseed oil as a concrete admixture, also at dosages above 1.5 %. The research should focus on rapeseed oil as hydrophobizing

agent, but also on its effect on other interesting concrete properties for COIN; like hardening retarder, shrinkage reducing agents, electrical resistivity and pH reduction.

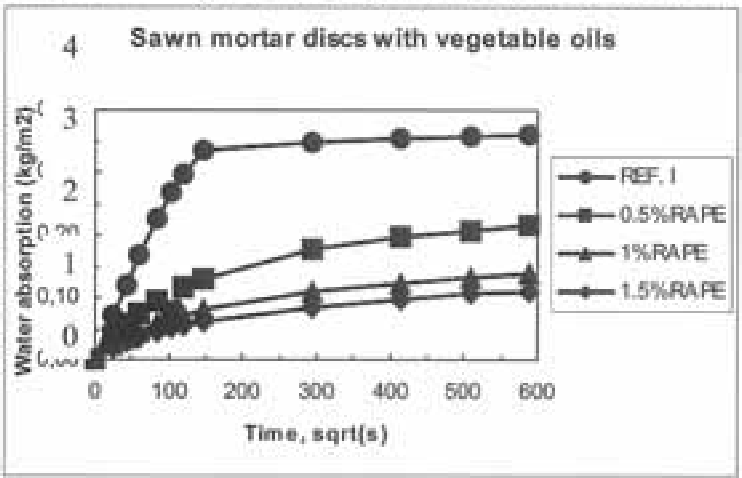

Figure 1 – Water absorption of sawn mortar discs with 0.0, 0.5, 1.0 and 1.5 % rapeseed oil added.

3. PROJECT DATA

COIN - Concrete Innovation Centre - is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology (NTNU) and industry partners work in the COIN projects (presently 5 projects). COIN involves moreover 15 - 20 PhD-students, 10 - 20 M.Sc.-students and international guest researchers. The research covers a wide range of research topics.

COIN has a budget of NOK 200 millION over 8 years (from 2007), and is financed by the Research Council of Norway (~ 40 %), industrial partners (~ 45 %) and by SINTEF Building and Infrastructure and, NTNU (in all approx 15 %). The present COIN partners are the Research Council of Norway, SINTEF, NTNU, Norcem, Unicon, Maxit Group, Borregaard, Spenncon, Rescon Mapei, The Norwegian Public Roads Administration, Veidekke and Aker Kværner.
For more information, log on to www.sintef.no/coin

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Concrete with reduced cracking

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Key words: admixtures, additives, cracking, fibers, internal curing

1. INTRODUCTION

In 2007, 3 state-of-the-art reports (STARs) within COIN – the Concrete Innovation centre - were made on different approaches to achieve concrete with less cracking; 1) "Reduced cracking by admixtures and additives" [1] covering shrinkage reducing admixtures (SRAs) and expansive agents, 2) "Reduced cracking by fibers" [2] encompassing the use of fibers to reduce crack width and 3) "Reduced cracking by internal curing" [3] dealing with mitigation of shrinkage cracks caused by for instance self-desiccation using internal water reservoirs like saturated fine light weight aggregate (LWA) or cellulose fibers. This paper summarizes the findings from these 3 STARs and directions for research within this activity for coming years.

2. LITERATURE STUDY AND CONCLUSIONS

The 1st STAR [1] presents a literature review on mitigation of autogenous and drying shrinkage cracking by shrinkage reducing agents (SRAs) as well as expansive additives. The SRAs are often propylene glycol derivatives believed to function by lowering the surface tension of water and thereby the tensile stresses, but the mechanism is disputed. Expansive agents are usually formulations that produce ettringite, but reports are also found on hydroxide forming compound like lime (CaO) and periclase (MgO). There seems to be an interesting synergy in combinations of glycol based SRA and CaO expanding agent, which should be further investigated for practical applications within COIN. A third class of expanding additives is gas forming admixtures, in particular aluminium powder generating hydrogen gas. However, these additives seem more difficult to control in terms of timing and expansion.

The 2nd STAR [2] showed that non-metallic fibers added to concrete in general have considerably reducing effect on the early-age cracking. When the effect of non-metallic fiber is compared with ordinary mesh reinforcement, the fiber reinforcement shows the best results. It is also found that longer fibers have better effect than shorter fibers, probably due to better bond strength between concrete and fiber. The optimum fiber length is found to be somewhat larger than the maximum aggregate size. Non-metallic fiber added to concrete at fiber dosages of 0.5vol% can eliminate the problem with plastic shrinkage cracking, without reducing the workability considerably.

The 3[rd] STAR [3] on mitigation of autogenous shrinkage cracking by internal curing (i.e. internal supply of water NOT belonging to the mix water) of concrete revealed that the use of saturated, surface dry (SSD) lightweight aggregate (LWA) is proven to work as internal curing agent relieving stresses in concrete. It is now also used in practice in USA to combat shrinkage cracking in pavements and slabs. There seems to be a size effect, so SSD LWA as internal curing agent functions better in practice with large objects than in laboratory investigations on small specimens. However, the potential of saturating the LWA with solutions of admixtures (e.g. shrinkage reducing admixture) that otherwise would interfere with the initial setting and hardening has not yet been fully exploited and is recommended for pursuit in COIN. Very limited investigations have been performed on water saturated derivatives of wood; from wood powder, through cellulose fibres to cellulose derivatives, as agents for internal curing. Further research may be focused on water saturated cellulose fibers in order to elucidate the potential combination of internal curing and fiber reinforcement to mitigate shrinkage cracking.

3. PROJECT DATA

COIN – Concrete Innovation Centre – is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

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Nanosilica as Accelerator in Cement and Concrete

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Key words: nanosilica, accelerators, early hydration.

1. INTRODUCTION

The aim of the project was to study the effect of different accelerators on the early cement hydration and to better understand the mechanism of the acceleration period, which means what hinders the reactions to start immediately and what get them to start. Thereby you can better control the hydration and early strength development.

Nanosilica is a rather new material for concrete and has shown to give an accelerating effect on hydration of Portland cement. Nanosilica is colloidal SiO_2 with particle sizes between 1 and 500 nm. The particles consist of an amorphous shell with a hydroxylated surface.

Nanosilica with smaller medium size of the particles is more effective than nanosilica with coarser size. The accelerating effect can be increased by addition of alkali hydroxides or Ca-based accelerators. Experiments have been made with different types of nanosilica and Portland cements, mainly by using an isotherm calorimeter. The optimum amount of nanosilica regarding the heat evolved during the first five hours is different for different cements. The amount ranges from about 0,5-2,0 % as dry content of nanosilica of the cement weight depending on the cement type.

Also concretes with nanosilica were cast and the early strength at six hours was markedly increased for the concrete with high cement content.

This paper summarises the part of the study on the accelerating effect of different types of nanosilica with different Portland cements. The research project was one of the long-term programs at CBI, where the effect of accelerators on the early hydration was studied.

2. EXPERIMENTS

An isotherm calorimeter was used for measuring the heat development for the different cement pastes. Also some XRD-, SEM- and pore solution analysis were made. The effect on the compressive strength was measured on concrete.

Cements used were the Swedish low heat cement CEM I 42,5 N, a rapid hardening cement CEM I 52,5 R and cement based at the same clinker as the Swedish ordinary cement CEM II/A-LL 42,5 R, but without limestone filler, here called laboratory cement.

SiO_2 content and mean particle diameter for different types of nanosilica are given in table 1.

Table 1. Dry content of SiO_2 and mean particle diameter for different types of nanosilica.

	Nanosilica A	Nanosilica B	Nanosilica C
SiO_2 ,%	50	15	15
Mean particle diameter, nm	35	5	3,6

3. RESULTS

The nanosilica with the smallest particle size gives the highest acceleration effect with the lowest amount, Figure 1.

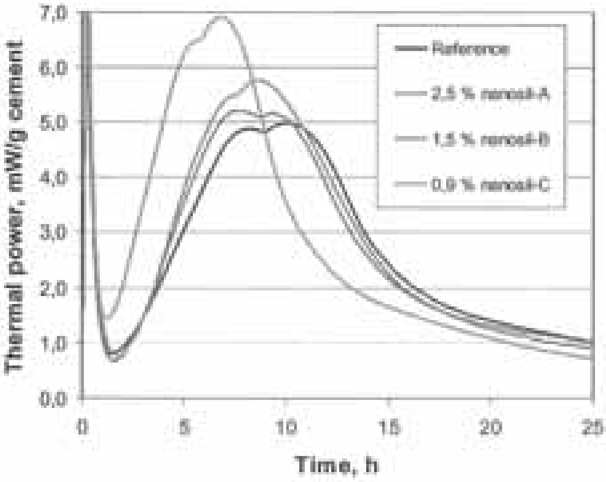

Figure 1. The effect of different amounts and types of nanosilica in rapid hardening cement.

4. CONCLUSIONS

The smaller the size of the nanosilica particles the less is the amount needed to get a certain acceleration effect. The effect is still accelerated with alkali hydroxides or Ca-bearing compounds. With high enough amounts of alkali hydroxides even ordinary silica fume becomes an accelerator. The accelerating effect seems to be a result of the solubility of the silica. For low heat cement the content of nanosilica should be increased to get a higher accelerating effect compared to ordinary and rapid hardening cement. For concretes with high amounts of rapid hardening cement the compressive strength at six hours increased from 3,6 MPa without nanosilica to 33,1 MPa with 1,5 % nanosilika as dry content of the cement weight. For concretes with lower cement contents of ordinary Portland cement the increase in compressive strength with nanosilica was only a few MPa.

From Set Retarders to Hardening Retarders: A New Concrete R&D Challenge

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Keywords: Concrete, admixtures, retarders, setting, hardening.

1 INTRODUCTION

Retarding admixtures are used to produce a controlled delay of the setting of cement. Hence, a retarder is added to a concrete mix in order to prelong setting time and workability time. Once the setting has occurred, the rate of hardening is normally not affected. Many organic and inorganic admixtures have proved successful for this purpose in concrete. Consequently, very few research efforts on the development of new set retarders are seen. However, there is a need for retarders that are capable of decreasing the rate of cement hydration after setting has occurred. Today, only *setting retarders* are commercially available, while *hardening retarders* are not promoted in the market.

In the Norwegian COIN project (see Section 4) one goal is to develop *hardening* retarders for concrete. Accordingly, a state-of-the-art-report [1] has been written providing a historical and technical overview of retarders in general, their mode of actions, the characteristics of today's commercial retarders, and attempts at developing hardening retarders. This report is a short presentation of the COIN State-of-the-art-report.

2 RESEARCH SIGNIFICANCE

It is quite easy to retard *setting* of cement by chemical admixtures. Several well known set retarding admixtures are on the market. Even though a considerable amount of work has been carried out to explain the mechanisms of action of these retarders, there are still some divergences.

It is much more difficult to retard *hardening* of concrete by admixtures. There are no hardening retarders on the market. For some concreting operations it is considered important to lower the rate of heat evolution during the hydration of the cement, e.g. in massive concrete structures to minimize the risk of thermal cracks.

3 RESULTS AND CONCLUSIONS

Set retarding admixtures are mainly found among organic compounds, but inorganic chemicals may also act as retarders.

Organic chemicals
Lignosulphonates, hydroxycarboxylic acid and their salts, phosphonates, and sugars

Inorganic chemicals
Phosphates

Sodium gluconate (hydroxycarboxylic salt) and phosphate are the most common ingredients in today's commercial retarders.

The mechanisms of action of retarders may differ and are divided into four types of interaction: Adsorption, precipitation, complexation and nucleation.

Retarders to decrease the rate of hardening are not commercially available, but some research activities are reported. Research and development along this line will continue in the COIN project. The research should aim at investigating the capability of chemicals to slow down the temperature rise of cement hydration to produce 'low heat concrete'

4 PROJECT DATA AND FINANCIAL SUPPORT

COIN – Concrete Innovation Centre – is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology (NTNU) and industry partners work in the COIN projects (presently 5 projects). COIN involves moreover 15 - 20 PhD-students, 10 - 20 M.Sci-students and international guest researchers. The research covers a wide range of topics wherein *Advanced cementing materials and admixtures* is one of them.

COIN has presently a budget of NOK 200 million over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %). The present industrial partners are:
Aker Kværner Engineering and Technology, Borregaard LignoTech, Maxit Group, Norcem A.S, Norwegian Public Roads Administration, Rescon Mapei AS, Spenncon AS, Unicon AS and Veidekke ASA.

For more information, see www.sintef.no/coin

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Sea Dredged Gravel versus Crushed Granite as Coarse Aggregate for Self Compacting Concrete in Aggressive Environment

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Keywords: Self compacting concrete, coarse aggregate, sea dredged gravel, crushed granite, mechanical properties, durability, freeze-thaw scaling resistance, porous flint.

1. INTRODUCTION

In Denmark, sea dredged gravel is the material most frequently use das coarse aggregate in concrete, including in self compacting concrete (SCC). However, when the concrete is to be exposed to severely aggressive environments the current standards exclusively allow crushed granite to be used [1]. The main reason for this is that even a small proportion of lighter and porous gravel particles can be suspected to adversely affect the durability of the concrete in terms of frost damage or alkali silica reaction. In addition, the mechanical properties of the concrete may be affected by the characteristics of the coarse aggregate. The two types of aggregate differwidely as regards the shape of the particles. The sea gravel consists predominantly of rounded and smooth particles, where as the crushed granite particles are angular and have a rough surface. It has been investigated whether it is possible to use sea dredged gravel instead of crushed granite to a greater extend than previously assumed.

2. RESEARCH SIGNIFICANCE

Danish concrete suppliers would benefit from avoiding the handling and storage of crushed granite coarse aggregate which is presently used for severely aggressive environments only. Thereby they would be able to use domestic aggregate materials for the majority of the projects.

3. METHOD

The basis of the mix designs chosen in the project was to fulfil the code requirements [1] of aconcrete to serve in "aggressive" (Class A) and in "extra aggressive" (Class E) environment, and in addition it was chosen to include a high performance concrete(HPC) having a still higher strength and durability level. Thus, three pairs of concrete mixes were prepared (Water to binder ratios 0.40, 0.36 and 0.28), each pair constituting one concrete with sea gravel and one with crushed granite coarse aggregate. All mixes where designed to have a slump flow of about 600 mm and an air content of about 5 %. The binder composition was the same in all mixes: 80 %

cement, 15 % fly ash and 5 % microsilica. The following properties were measured: Compressive strength, flexural strength, tensile splitting strength, modulus of elasticity, freeze-thaw scaling resistance of concrete specimens and freeze-thaw resistance of the coarse aggregate itself.

4. RESULTS AND CONCLUSIONS

At equal flow properties SCC with sea gravel had an aggregate content of 67 % by volume as compared to 64% with crushed granite. This contributed to the modulus of elasticity of the concretes being systematically 20-30 % higher with the higher content of sea gravel aggregate.

Tensile splitting strength, flexural strength, and compressive strength all showed the same pattern: At the highest w/b (0.40) the SCC with sea gravel exhibited significantly lower values than the SCC with crushed granite, where as the opposite was the case at the lowest w/b (0.28). This is believed to be due to the characteristics of the interfacial zone between the hardened paste and the aggregate particle surfaces: At high w/b the paste phase is more porous and the undulations of the rough granite surface acts as shear keys resisting propagation of cracks along the aggregate surface, much more so than is the case for the smoother sea gravel particles. At low w/b, however, the interfacial zone is denser and has a finer microstructure which is able to provide a strong connection to the surface of the smooth sea gravel particles which in turn arestronger than the crushed granite particles.

The resistance against freeze-thaw scaling in the presence of deicing agents was best with crushed granite coarse aggregate. It was found that porphyry and iron-bearing sandstone particles in the sea gravel caused pop-outs in the surface and were prone to disintegration during freezing and thawing. This occurred to such an extent that the sea gravel concretes for aggressive and extra aggressive environments failed to meet the requirements of the standard. Porous flint present in the sea gravel, however, which was initially suspected to be problematic,did not seem to adversely affect the freeze-thaw scaling resistance of the concrete.

5. PROJECT DATA AND FINANCIAL SUPPORT

The present paper is based on a Master Thesis from Aalborg University [2]. The Thesis work lasted one year and was completed in June 2006. Materials for the experimental work was kindly sponsored by cement supplier Aalborg Portland A/S, concrete supplier Unicon A/S and aggregate supplier Krohgs A/S

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Geological Properties Controlling the Production of Concrete with Manufactured Sand

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1. INTRODUCTION

Crushed rock becomes more and more common as aggregate in concrete, due to the restriction to use natural gravel. Today, crushed rock is commonly used from the size of 8 mm and upwards. Sand and gravel is still the main source for the finer grading. The problem with using crushed aggregate for the finer fractions is the often too flaky and elongated shape of the particles, especially in the 0-2 mm fraction, but also the grading curve is different with a higher content of fines compared to natural sand. This leads to a more low viscous fresh concrete which means that more cement and water must be added to the mix. This paper gives a short description of the geological properties that control these parameters, and how it is possible to improve the material characteristics in the crushing process.

1.2 Grain shape

The shape of the particles is probably the most important aggregate parameter for the rheology of the concrete. The main parameters that influence the shape of the crushed particles are the mineralogy together with the size and shape of the minerals in the rock. A rock with high mica content should be avoided since mica is the mineral which creates most flaky particles (Figure 1).

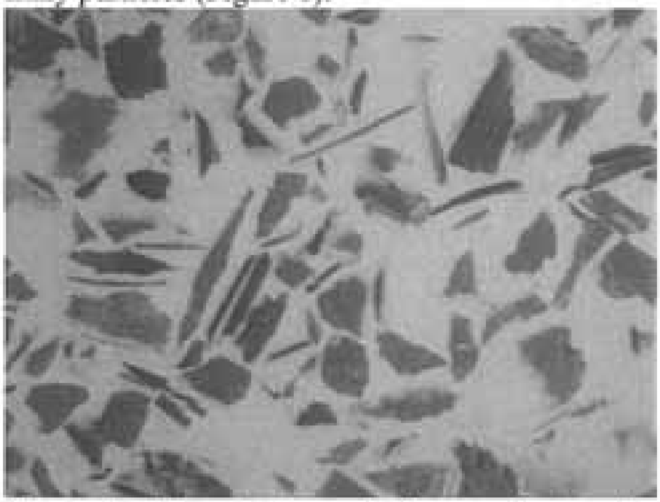

Figure 1 – Microphotograph of a manufactured sand of the 0.25-0.5 mm fraction, produced from a granite with approximately 20 % mica. This material have a Fmin/Fmax of 0.46. The image size is 2.8x2.1 mm.

The reason why the size of the minerals in the rock is important is that when the rock material is crushed it breaks in the weakest planes, which are along straight planes inside the mineral resulting in flaky particles. This means that a fine grained rock has better conditions to form a more rounded material. To characterise the geometry image analysis on microscopic images is a suitable tool. The parameter that is measured is the length to breadth, expressed as the ratio Fmin/Fmax [1]. Natural sand has normally a ratio around 0.6-0.65, whereas manufactured sand has a greater range, from 0.45 to 0.6. Crushed sand should at least have grain shape with median values around 0.55 to make a good concrete.

1.2 Grain size distribution

Natural sand and gravel have a very suitable size distribution for concrete. Today, a 0/8 mm grading can be used without doing any improvements of the sieving curve. This is not possible with manufactured sand. The proportion of the different fraction is very different compared to natural sand, especially in the filler fraction (< 0.063 mm). In order to proportion a curve similar to natural gravel, aggregate must be sieved in more narrowed fractions.

1.3 Optimisation of size and shape parameters

It is very important to choose the right rock material. However, a rock material with good properties can be useless if the procedure in the crushing plant is unsuitable. Cone crushers are most frequently used in the aggregate industry. A disadvantage with the cone crusher is that it is produce aggregate with poor shape in most size fractions. It is possible to improve the particle shape by using a vertical shaft impact crusher (VSI) in the last stage of the crushing plant. A VSI can produce more cubic particles at least down to the mineral size of the rock (Figure 2). Bengtsson [2] showed that the rotation speed of the VSI is very important for the shape of the material. A disadvantage with the VSI is the tendency to produce more fines and also that the shape of the particles < 0.063 mm could be more flaky compared to a cone crusher. The optimal procedure is to combine the VSI with wind sieve that takes away the fines and also provides the possibility to separate flaky minerals such as mica.

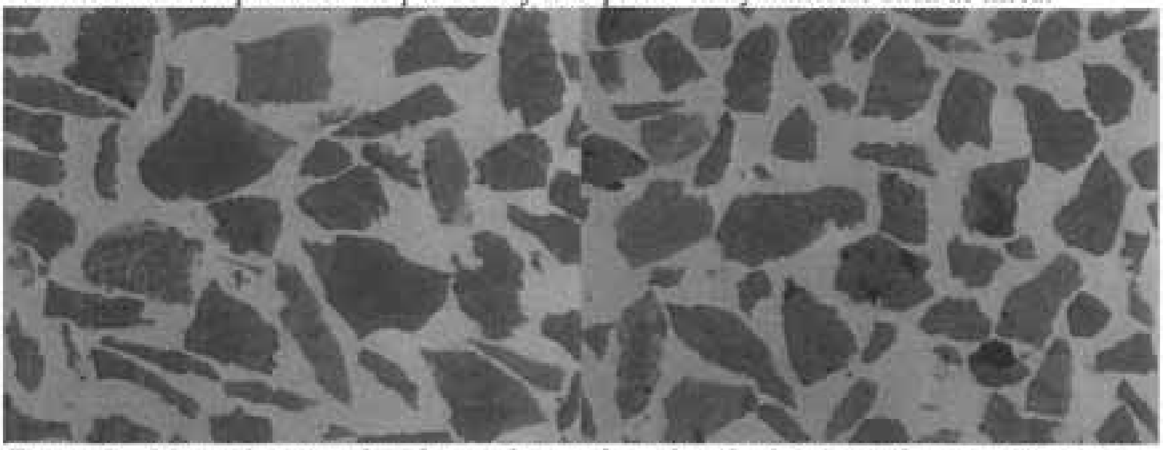

Figure 2 – Microphotographs of manufactured sand in the 0.5-1 mm fraction. The image show the difference between cone crushed (left) and VSI crushed (right) manufactured sand.

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Nonlinear Modelling of Packing of Aggregates of Three Sizes for Minimising Cement Consumption

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1. INTRODUCTION

To minimise cement consumption in concrete, aggregates should be packed themselves leaving the smallest volume of voids. Voidage can be reduced by simply mixing particles of two or more different sizes in suitable amounts. This work focusses on minimising the voidage in compacted mixtures of aggregates of three sizes. The technical raw materials exhibit variable particle size distributions and particle shapes. The attempt to predict mix behavior by simple characterization of the individual components is thus very difficult. The packing properties of a single component can be measured easily, but the interaction with other components are significant, and cannot be predicted well based entirely on separate packing of each component. Therefore, a method for combining a reasonable number of accurate volume measurements with a suitable mathematical model has been developed.

2. NONLINEAR MODELLING

Nonlinear modelling has been around for more than fifteen years. It has been successfully utilised by various industries for a variety of purposes from process development, product development to software sensors and fault detection.

Nonlinear modelling can roughly be defined as empirical or semi-empirical modelling which takes at least some nonlinearities into account. Nonlinear modelling can be performed in many ways. The simpler ways include polynomial regression and linear regression with nonlinear terms. One can also use basis functions and splines, and in cases where the form of the nonlinearities is known, nonlinear regression can also be used. New techniques of nonlinear modelling are based on free-form nonlinearities and do not require the knowledge of the form of nonlinearities in advance.

3. EXPERIMENTAL DATA

A total of 13 experiments were carried out on 11 January 2008 with different amounts of fine, medium and coarse aggregates. The aggregates had a fair variation in the particle sizes, and their shapes were far from spherical. The required amounts for each experiment were weighed and then manually mixed in a plastic bag before loading into an IC tester. The IC tester was run for a certain compaction effort for a fixed number of cycles and with a fixed pressure. Voidage in the experiments varied from 0.215 to 0.389.

4. RESULTS

A nonlinear model for predicting voidage with ten parameters was developed from the experimental data. The rms error (roughly the standard deviation of the prediction errors) was 0.0025448, which amounts to a correlation coefficient of 99.80%. The largest error was 0.0065567. Figure 1 shows the contours of voidage on a triangular plot.

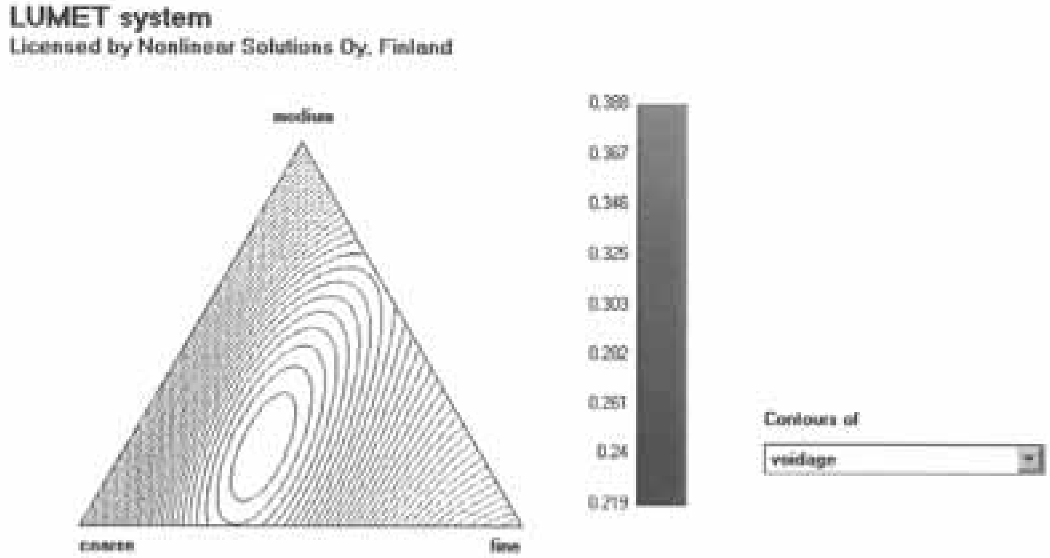

Figure 1 – Contours of voidage calculated from the nonlinear model.

5. CONCLUSIONS

Development of sufficiently accurate mathematical models of voidage or relative volume has been considered difficult. This work demonstrates that nonlinear modelling is not only highly effective but it does not require a large number of experiments either. Nonlinear models were developed from a series of 13 experiments on mixes of aggregates of three sizes. The model shows a correlation coefficient of 99.8%.

Session B4
Numerical Methods

Comparative Numerical Studies of Projectile Impacts on Plain and Steel-fibre Reinforced Concrete

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Key words: Numerical simulation, projectile impact, steel-fibre reinforced concrete.

1. INTRODUCTION AND RESEARCH SIGNIFICANCE

The enhanced energy absorption characteristics of steel-fibre reinforced concrete, compared to plain concrete, motivates its increased usage in protective structures. However, the structural behaviours of concrete elements subjected to impact are complicated and it is not completely understood how the impact resistance is influenced if steel-fibres are added into the concrete mix. In order to improve this understanding numerical studies of projectile penetration into plain and steel-fibre reinforced concrete have been conducted.

2. METHOD

The hydrocode AUTODYN 2D [1] was used to simulate the projectile penetration into plain and steel-fibre reinforced concrete, where the effect of fibres in the concrete was limited to an improved post-cracking behaviour in the numerical model, i.e. increased fracture energies, G_F. However, the results were believed to give the overall behaviour of projectile impact on fibre-reinforced concrete compared to plain concrete. Three different mixes of fibre-reinforced concrete, four different target lengths and two different projectiles with differing striking velocities were used.

3. RESULTS

In Figure 1 the results from simulations, where flat-nosed projectiles strikes three different concrete cylinders with velocities of 650 m/s, are shown. These results, and the conclusions drawn from them, are in many ways representative for most results within the study. The depth of penetration is negligibly affected by the addition of steel-fibres in the concrete, but a small reduction can be seen. Both the front- and rear-face crater sizes are reduced and the rear-face crater in the case shown in Figure 1, is even prevented when fibres are added into the concrete.

The decrease of the front-face crater is less considerable than the decrease of the rear-face crater. In the simulations where an ogive-nosed projectile was used the formation of a rear-face crater could not be differentiated from penetration of the concrete target.

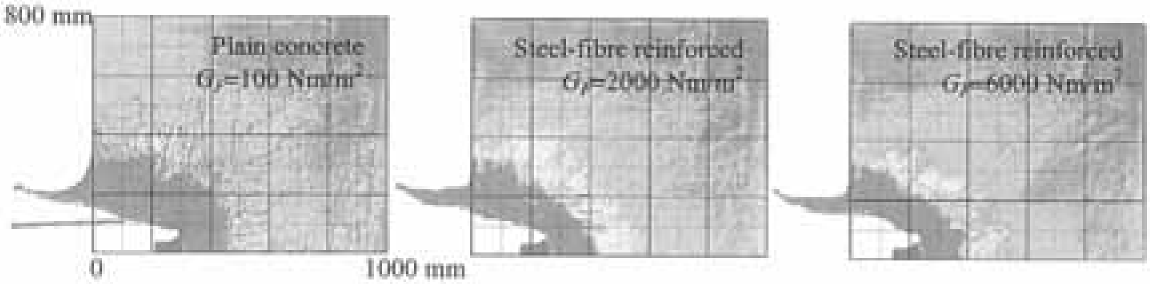

Figure 1 – Simulation results for plain and steel-fibre reinforced concrete.

4. CONCLUSIONS

The addition of moderate dosages (<1%) of steel fibres into plain concrete gives:

- A negligible decrease of projectile-penetration depth compared to plain concrete.
- Reduced front- and rear-face crater diameters, but where the effect on the rear face crater is larger than on the front face.
- More localized damage, i.e. reduced crack propagation beyond the crater region.

The results also indicate that the rear-face crater may be prevented by use of steel fibres if it is due to the reflected stress wave caused by the impact alone and not in combination with the shear-plugging effects from the projectile.

5. FINANCIAL SUPPORT

The project is financially supported by the Swedish Rescue Services Agency.

6. PROJECT DATA

This is a substudy within a project whose long-term aim is to study and increase the knowledge of blast and fragment impacts on reinforced concrete. The research project is a collaboration of many years' duration between Chalmers University of Technology and the Swedish Rescue Services Agency. In earlier studies within the framework of this project, the effect of blast waves in reinforced concrete structures, fragment impacts on plain concrete and reinforced concrete subjected to projectile impacts were studied.

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Applying Fracture Mechanics on FRC Beams, Material Testing and Structural Analysis

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Keywords: fibre-reinforced concrete, fracture mechanics, stress-crack opening relationship, inverse analysis.

1 INTRODUCTION

Fibre-reinforced concrete (FRC) is a cement-based composite material reinforced with discrete, usually randomly distributed, fibres. For most structural purposes steel fibres are the most used ones. Fibre reinforcement mainly enhances the post-cracking properties of concrete and leads to a more ductile material behaviour. The increased ductility is due to the ability of the fibres to transfer tensile stresses across a cracked section; potentially leading to a reduction in crack widths.

2 RESEARCH SIGNIFICANCE

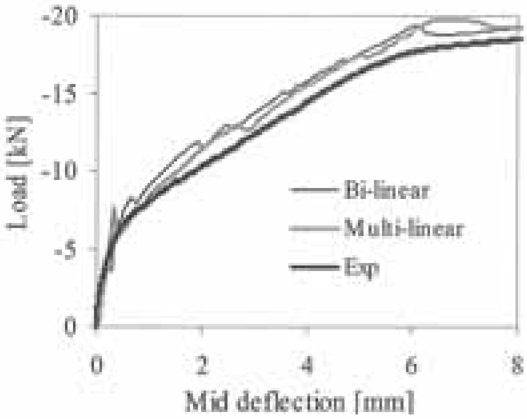
The number of practical applications of fibre-reinforced concrete (FRC) is increasing as FRC offers a possibility to greatly simplify in-situ cast concrete construction. However, general design guidelines which take into account the material properties characteristic of FRC are needed. The currently available design methods are based on rather rough simplifications regarding the stress-strain relationships (e.g. [1]); thus they are probably better suited for calculations in the ultimate limit state. The present work has been focused on the small cracks occurring in the serviceability limit state (SLS), taking the tensile material characteristics of the used FRC into consideration, [2].

3 METHOD

The work has been focused on strain-softening FRC and interrelationship between material properties and structural behaviour. The purpose of the present study was to investigate, by means of experiments and non-linear fracture mechanics analyses, the flexural behaviour of reinforced FRC beams made of self-compacting FRC, reinforced with a combination of steel fibres and conventional bar reinforcement. A systematic approach for material testing and structural analysis, based on fracture mechanics, has been used. A comparison between bi-linear and multi-linear stress-crack opening (σ-w) relationship was done in order to investigate wich one that is better suited for studying of the cracking process.

4 RESULTS AND CONCLUSIONS

Load-deflection curves from analyses using a bi-linear s-w relationship show the same agreement with experimental curves as the results from using a multi-linear one. From the obtained crack patterns though, the indication is that using a multi-linear σ-w relationship yields a more distinct crack pattern with somewhat better agreement with experiments. Figure 1 shows load-deflection curve up to peak load, Figure 2 shows crack pattern (a) for bi-linear, and (b) for multi-linear s-w relationship. (Results from beam with fibre content by volume V_f = 0.5% and three rebars of diameter 6 mm.)



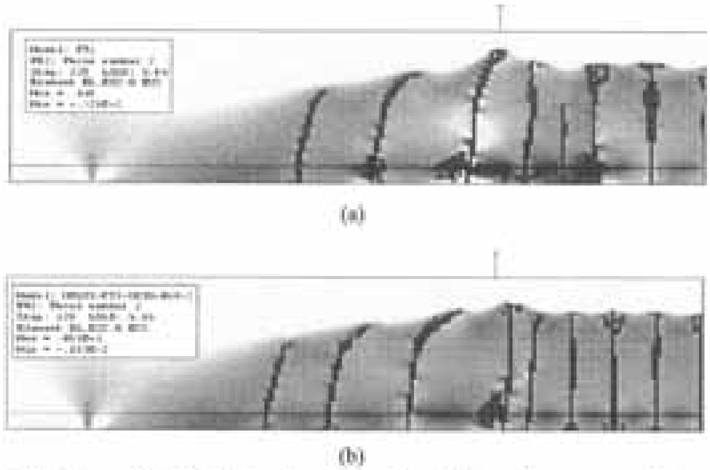


Figure 1 – A bi-linear σ-w relationship is fully sufficient for focus on load-bearing capacity. For focus on crack widths in the SLS, a multi-linear σ-w relationship appears to better describe the cracking procedure. To conclude this, further research is needed (left).

Figure 2 – To be able to predict crack widths in SLS, it is necessary to increase knowledge of bond-slip behaviour of FRC and also to gain better understanding of how to accurately estimate the characteristic length (right).

5 PROJECT DATA AND FINANCIAL SUPPORT

This is a Ph.D. project between February 2006 and February 2011, financed through a donation from Thomas Concrete Group AB, Göteborg, Sweden.

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FE Analysis of Cracking in Concrete due to Shear Loading

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Key words: Finite elements, fracture, shear, crack width.

1. INTRODUCTION

Shear type failure in concrete is often complicated to calculate due to its brittle nature. The strongly non-linear behaviour results in a significant drop in load carrying capacity which usually leads to numerical convergence difficulties. There are several different constitutive models developed to describe the behaviour of concrete. A realistic model of the concrete behaviour enables accurate simulation of actual structural behaviour in service and in ultimate limit state. In this paper non-linear finite element (FE) analyses of concrete beams subjected to in-plane forces resulting in a shear type failure are performed with different continuum based concrete models.

2. RESEARCH SIGNIFICANCE

The work aims at describing shear type crack initiation and propagation in concrete with finite element analyses.

3. METHOD

To study the capability to model the behaviour at shear failure with different FE packages, analyses were performed based on experimentally tested deep beams [1]. All the beams had the same geometry and consisted of an I-shaped cross-section, but differed in the amount of web reinforcement. The material models used for analyses treat cracked concrete as a continuum where the cracks are distributed over the element. The elements describe both the elastic part of the uncracked concrete and the inelastic deformation due to cracking. In the models made with *Atena 2D* the material definition *SBETA* was used, with either a fixed or a rotated crack direction. In *Response* a rotated crack model was used. The *Abaqus* models were made with the material definition *concrete damaged plasticity* where the element is damaged in either tension or compression. The damage is isotropic, meaning that the "cracks" may be assumed to follow the principal strain direction.

4. RESULTS

In Figure 1 a), the deviations of the predicted ultimate load and deflection obtained with the three programs compared to the tests are illustrated. The fixed and the rotated model in *Atena*, and the *Response* models give too stiff estimations of the behaviour. In the *Abaqus* models the predicted stiffness corresponds well with the experimental one. All analyses had similar mean accuracy in the prediction of the ultimate load. The analyses showed that, the material models in *Response* and *Atena* based on a rotating crack approach resulted in much smaller crack widths than experimentally obtained. The damaged plasticity model and the fixed crack approach gave crack width predictions that were much more accurate [2], see Figure 1 b).

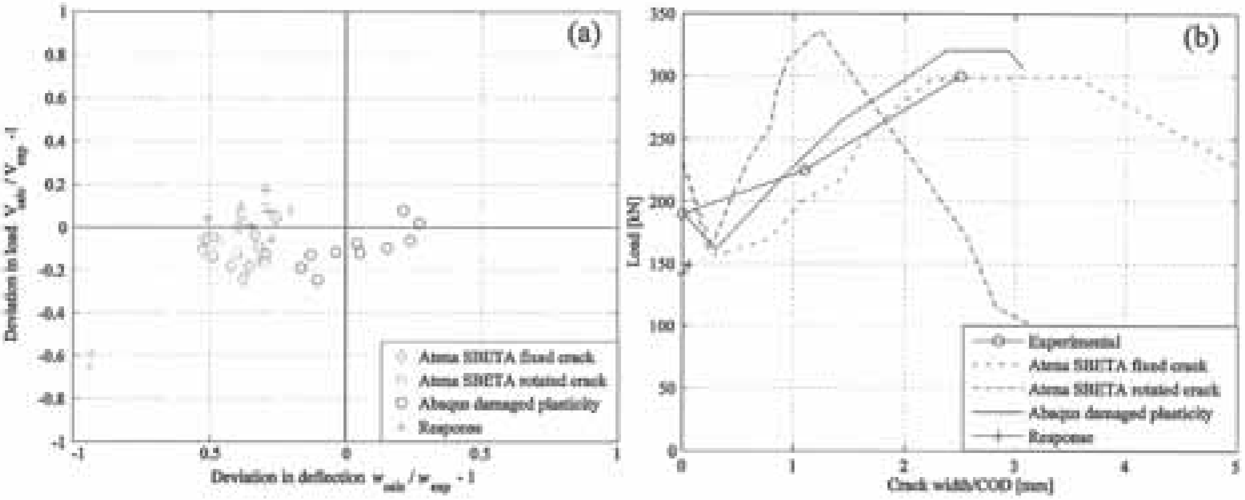

Figure 1 – Numerical analyses compared to experiments. a) Deviations in load and deflection. b) Load and crack width (COD) of a beam without web reinforcement.

5. CONCLUSIONS

The analyses with the different numerical programs showed good agreement with the measured ultimate load. The exception was the unreinforced beams that could not be predicted accurately with *Response*. The fixed and the rotated models in *Atena* and the *Response* model gave deflections that were smaller than the experimentally obtained ones. Crack widths can be calculated with reasonable accuracy with the plasticity model in *Abaqus* and the fixed crack model in *Atena*. The crack pattern obtained with all finite element models corresponded well with the pattern from the experiments.

6. PROJECT DATA

This work was performed in 2007 and is part of a doctoral project, financially supported by FORMAS.

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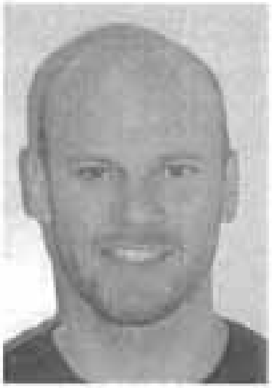
Interpretation of Fatigue Mechanisms by Mans of a Meso-Scale Model



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Key words: Cyclic loading, Concrete, Constitutive model, Meso-scale, Lattice model

1. GENERAL DESCRIPTION

Concrete subjected to cyclic loading has a strongly non-linear response that gives characteristic unloading and reloading paths seen in fatigue experiments [1]. This difference in loading paths is called hysteresis loops. The non-linear response stems from fracture of the weak interfacial zones between mortar and aggregates and localisation of deformations in the mortar matrix.

The combination of the theory of plasticity and damage mechanics can describe permanent deformations and the reduction of stiffess observed in experiments [2,3,4]. This combination is often used for macroscopic phenomenological models for concrete subjected to cyclic loading, which can reproduce the experimental results for specific load cases, but cannot model the underlying mechanics which are the cause for the experimental observed hysteresis loops.

In this study the non-linear response is described by modelling of mortar and interfacial transition zones between mortar and aggregates. The constitutive law based on a combination of damage and plasticity describes the loss of stiffness and irreversible strains. The unloading-reloading path is the same on the constitutive level and the hysteresis loops are described by the mechanical interpretation of the different phases. A phenomenological softening stress-strainrelationship is used for the mortar and interfacial zone. The purpose of this study is to investigate parameters infuencing the size and shape of the hysteresis loops and energy dissipation, such as aggregate size, aggregate density and the parameter that controls the unloading stiffness.

Five different material parameters are considered in three different parts of the parametric study. The first part considers aggregate size and density, which are material parameters that define the distribution of phases in the structure. The second part considers the hardening parameter of mortar and inter facial transition zone (ITZ), which is a material parameter that influences the unloading stiffness according to[5,6]. The final part considers the ratio of ITZ/mortar strength which effect the material strength and the unloading stiffness.

2. CONCLUSIONS

In the present study it is found that decreased aggregate density increases the ultimate strength and decreases the fracture energy of the material, because of the decreasing amount of interfacial-zones. However, a decreasing amount of interfacial-zones results in an increased unloading stiffness. It is also observed that an increase of the ITZ-hardening parameter results in larger sized hysteresis loops, but an increase of the mortar-hardening parameter results in less unloading stiffness. Increasing the ITZ strength increases the unloading stiffness and the ultimate strength. The ultimate strength is also increased with increased aggregate-size range, because of an increased interaction between aggregates. It is believed that the proposed modelling has better predictive qualities compared to macroscopic phenomenological models, since the properties of the different phases are given as input and the influences of geometry and distribution of aggregates are considered.

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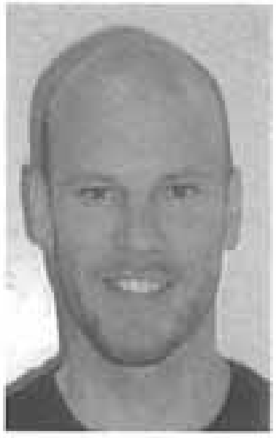
A Dual-Model Describing Concrete Subjected to Cyclic Loading



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Key words: Cyclic loading, Concrete, Constitutive model, Fatigue, Dual-model

1. INTRODUCTION

Cyclic loading of concrete results in a strongly nonlinear response represented by hysteresis loops, [1,2]. During the last decades there has been done research to develop phenomenological models that can describe the hysteresis loops and fatigue strength observed in experiments. The majority of these models are based on the concept of bounding surface[3], while others are based on special combinations of plasticity and damage, [4]. Recently, the fatigue phenomenon was investigated on the meso-scale level, [5]. Presented here is a new approach for describing fatigue of concrete: a dual-model that is based on the meso-scale investigations. The dual-model is represented by a plasticity-sub model and a damage-sub model and is therefore categorised as a model based on a special combination of plasticity and damage. Though, the novelty is found in the coupling between the damage-sub model and the plasticity-sub model by the stiffness ratio parameter and the hardening flexibility of the unloading-yield surfaces. In addition, the present dual-model predict the energy dissipation due to hysteresis loops, which are on the contrary to earlier models.

2. CONSTITUTIVE EQUATION AND RESPONSE

As mentioned the dual-model is represented by two sub-models: a plasticity-sub model and a damage-sub model. The sub-models use the same strain e when evaluating their contribution to the total stress state. The individual contribution to the total-nominal stress s of the dual-model is controlled by a stiffness ratio parameter a_E, which has two extremes: for $a_E = 0$ the dual-model acts as an isotropic-damage model, while for $a_E = 1$ the response of the dual model is plastic with plastic softening. The damage evolution of the damage-sub model is for compression and tension given by a scalar damage evolution parameter ω, thus the damage-sub model is an isotropic-damage model. The stress-strain relationship then becomes

$$s = (1- a_E)(1- \omega)D_e e + a_E D_e(e- e_p) \qquad (1)$$

where D_e is the elastic-stiffness matrix and e_p is the plastic strain of the plastic-sub model.

Yielding in the plastic-sub model is defined by three yield surfaces, as the model considers loading and unloading, as well as compression and tension. The loading-yield surface is chosen according to Ottosen's yield surface [6], while the unloading yield surfaces are separated for compression and tension and are chosen to be stress-volumetric dependent.

A main complexity when dealing with cyclic loading in 3D that alternates between compression and tension is to define which loading state that governs there sponse and when an alternation between loading states occurs. In the presentdual-model the governing loading state and load alternation is defined by the volumetric-strain e_v . The volumetric strain is convenient, because it is a known scalar at the beginning of the stress-return iteration and is stress-volumetric dependent.

The present model gives a new view of the complexity of the fatigue phenomenon and adds to the understanding of the mechanisms involved in cyclic loading.

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Non-linear FE Analyses of Prestressed Concrete Bridges Subjected to Shear and Torsion

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Key words: Non-linear finite element analysis, prestressed concrete, shear, torsion, bridge.

1. INTRODUCTION

Today, many existing prestressed concrete bridges are replaced or strengthened because their reliability cannot be proved based on the conventional structural assessments made. By using non-linear FE analysis for structural assessment, the load carrying capacity can be shown to be satisfactory, without costly investments. The resistance with respect to shear and torsion are in many cases limiting the load carrying capacity. In several research projects, failures due to shear and torsion have been successfully simulated. However, the method needed to be further verified in order to be practically applicable for bridge assessment.

2. ASSESSMENT OF THE KÄLLÖSUND BRIDGE AS A CASE STUDY

The aim of this study was to present an analysis method for evaluation of the load-carrying capacity of prestressed concrete bridges, when failure due to shear and torsion is the main problem. The modelling method used was first worked out and verified for shear-type cracking and shear failure [1]. Here, shell elements with embedded reinforcement were used together with non-linear material models, taking into account the fracture energy of cracking plain concrete and the reduction of the concrete compression strength due to lateral tensile strain. Analyses with the method proposed have shown to predict the shear response and the shear capacity of tested specimens conservatively. The load-carrying capacity of a box-girder bridge, the Källösund Bridge, was thereafter evaluated as a case study [2]. The whole bridge was modelled, but only the part that was most critical to shear and torsion was modelled in detail according to the method previously worked out and was combined with beam elements for the rest of the bridge.

The Källösund Bridge, used for the case study, has previously been evaluated both with conventional methods and with non-linear FE analysis [3]. The evaluation presented here was, compared to the previous one, improved in several respects. For instance, the modelling method used was verified, the final loading was made in a displacement-controlled process, effects of creep and reinforcement hardening were included, and safety formats suitable for non-linear analysis according to [4] were adopted. Here, two semi-probabilistic formats; the so-called ECOV method and the method presented in EN1992-2 [5] were used and compared with the deterministic format using partial safety factors.

Even if the shear resistance limited the load-carrying capacity in the previously performed assessment, the failure obtained in these FE analyses was due to bending. However, shear cracks developed in large regions of the webs; thus a shear response was observed and it could be concluded that the shear capacity of this part of the bridge, for this load combination, is higher than the load-carrying capacity determined. The FE analysis performed in this study revealed a load-carrying capacity corresponding to about 80% higher bogie load than in the previously made FE analysis, and over 100% higher than in a conventionally made assessment, see Table 1. The higher load-carrying capacity in the non-linear FE analysis, compared to conventional methods, is mainly governed by the location and inclination of the main shear crack. Most of the increased capacity compared with the previous FE analyses is probably due to the use of a more stable material model for cracked concrete and to the displacement-controlled loading. The analysis made with design values (partial safety factors) for all material properties gave a very conservative estimation of the load-carrying capacity.

Table 1 – Design resistance for combined shear and torsion, expressed as a bogie load.

	Previously made assessment		Assessment made in this study		
	Conventional	FEA	PSF	EN	ECOV
B_R [kN]	< 210	250	182	497	454

3. CONCLUSIONS

This study presents and demonstrates a verified modelling method that can be used for evaluation of the load-carrying capacity of prestressed concrete bridges when failure due to combined shear and torsion is the main problem; shell elements for the critical part of the bridge is combined with beam elements for the rest of the bridge. For the bridge studied, a substantially higher load-carrying capacity was shown compared with the previously made evaluations. Furthermore, it was shown that the safety format using partial safety factors gave unrealistically conservative results; it is more correct to use the semi-probabilistic formats for non-linear FE analysis.

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Lightweight Aggregate Concrete under Triaxial Compression

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Key words: Failure envelopes, lightweight aggregate concrete, triaxial compression

1. INTRODUCTION

Concrete exhibits strongly nonlinear and complex mechanical behaviour and is increasingly used in complex structures such as containment vessels, floating and submerged structures, and offshore structures. Hence, concrete structures are nowadays often analyzed by means of general finite-element programs. The finite-element method requires a good understanding of the actual material behaviour under different load combinations to yield accurate and realistic results. Investigations on concrete strength and deformations under multiaxial states of stress are therefore needed in order to establish the concrete strength criteria and realistic triaxial constitutive relations.

2. RESEARCH SIGNIFICANCE

In this study emphasis is placed on testing of the strength of lightweight aggregate concrete (LWAC), with varying density, under triaxial compressive loading. Even though LWAC has found a vast field of application in many types of structure and is subjected to multiaxial stress conditions, investigations of its failure characteristics under these conditions are very scarce. More experimental results are therefore needed to provide information for the development and validation of constitutive models. In addition, useful information about how the interplay between aggregate strength, mortar strength, and bond strength affects the behaviour of concrete can be obtained. Lightweight aggregates usually possess higher bond with cement mortar but lower intrinsic strength than nomal weight aggregates. These factors play an important role in many theories of concrete strength. The failure envelopes for LWAC tends towards an intersection with the hydrostatic axis, in contrast to normal aggregate concrete (NAC) where they are open ended, this indicates that LWAC may fail in some manner fundamentally different from NAC.

3. METHOD

For the measured values to be considered as unique and fundamental properties of the concrete, they must be obtained from tests which have produced the required stress conditions in the specimens, independent of any machine or testing effects. In this work a fluid cushion loading system is used. Three independently controlled principal compressive stresses are applied along orthogonal directions to a 100 mm cubical specimen. Loading by hydraulic fluid subjects the specimen to clearly defined uniform stress with no restraints imposed onto the specimen. The measured values can therefore be regarded as true material properties for the concrete.

4. RESULTS

So far, some data for NAC hasvebeen collected to verify the validity of the test method. More tests are required to draw conclusions, but the test rig seems to give reliable results. Failure envelopes for LWAC under triaxial compression will be reported later.

6. FINANCIAL SUPPORT

The financial support for the experiments was provided by the Concrete Innovation Centre (COIN), hosted by SINTEF.

7. PROJECT DATA

This work is part of a Ph.D. Thesis at NTNU, under supervision of professor Svein Ivar Sørensen and co-supervision of Helge Brå. It started in autumn 2005 and is planned to be finished by the end of 2009.

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Hybrid Concrete Structures – Use of Lightweight Concrete and Fibre-Reinforced Concrete in Beams

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Key words: Fibre-reinforced concrete, lightweight concrete, four-point bending test, finite element analysis

1. INTRODUCTION

At the Norwegian University of Science and Technology (NTNU) hybrid concrete beams have been tested [1]. The beams consist of a top layer of lightweight concrete with a cylindrical compressive strength of 38 MPa, and a 50 mm bottom layer of fibre-reinforced concrete. The beams are analyzed numerically by using the finite element code Diana [2].

2. RESEARCH SIGNIFICANCE

There is a continuous demand for improvement of structures due to economic considerations, better working conditions and environmental issues. Hence, it is important to develop new types of structures which optimize and utilize the properties of different materials. The presented hybrid structure has a low self-weight and the fibre-reinforcement contributes to a dense concrete.

3. METHOD

The experimental program comprehends six small beams (600x150x150 mm) and four larger beams (3000x250x150 mm). The large beams have 2ø8 bar reinforcement between the concrete layers. Two series of beams are investigated with either 3% synthetic macro fibres or 2% Dramix steel fibres. The beams were exposed to a four-point bending test where deflections and strains were measured.

In the numerical analyses a smeared rotating crack approach was employed. Based on the experiments, stress-strain relationships are calculated and used in the analyses.

4. RESULTS

The small beams developed one dominant crack at the beam's midpoint, while the large beams developed many cracks distributed along the mid-span. One large beam failed due to flexural behaviour, and three large beams experienced shear-failure.

The numerical analyses are capable of finding the maximum load levels and ultimate capacities, see Table 1. However, the corresponding deflections show greater variation compared with the experiments. Deformations are strongly influenced by the stress-strain relationship which in a smeared crack approach depends among other things on fracture energy and element size.

Table 1 – Results from four point bending tests.

Beam	Small beams				Large beams			
Fibre-reinforcement	Synthetic		Steel		Synthetic		Steel	
	Exp.	Analysis	Exp.	Analysis	Exp.	Analysis	Exp.	Analysis
Maximum load [kN]	31-39	35,3	53-59	55,8	27,2-31,5	26	34,6	31
Deflection [mm]	0,8-1,5	1,2	0,4-0,7	0,8	18,6-40,5	13	13,7	11,5

5. CONCLUSIONS

Experiments have been carried out on hybrid concrete beams with a layer of lightweight concrete and a layer of fibre-reinforced concrete. The response was dominated by one large crack and moment failures for the small beams. The large beams showed a distributed crack pattern and the ultimate capacity is governed by shear failures. Numerical analyses give results which are in accordance with the experiments.

6. FINANCIAL SUPPORT

The financial support is provided by the Concrete Innovation Centre, COIN [3].

7. PROJECT DATA

This work is carried out as a part of a Ph.D. project started in autumn 2007. Anticipated final day for the project is autumn 2011.

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Redistribution of Moments and Forces from Linear FE Analysis: Recommendations for Design and Assessment of Slab Bridges

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1. INTRODUCTION

FE structural analysis can rationalise and improve bridge assessment and design, in particular for complicated geometries where modelling in three dimensions is required. Due to moving loads and the large amount of different load cases, linear analysis is normally used for bridges. Linear analysis often leads to high stress concentrations, e.g. at point supports or slab-column connections. These are often expressed as concentrated cross-sectional moments and shear forces.

However, the stress concentrations obtained through linear analyses of concrete bridges do seldom exist in reality. This is due to the cracking of the concrete, often already for service loads, and the yielding of the reinforcement in the ultimate limit state, leading to even larger re-distribution of moments and shear forces. Another reason for unrealistic stress concentrations in linear analysis can be due to idealisations of the geometry when structural elements like slabs and beams are used to model the bridge.

The objective of this part of the project was to develop general recommendations for how concentrations of cross-sectional moments and shear forces, obtained by linear FE analysis, can be redistributed when designing or assessing concrete bridges in ultimate and service limit states. The study focused on slab bridges and on the moments and shear forces at concentrated supports. A state-of-the-art investigation was made and different recommendations regarding distribution of reinforcement in slabs were studied. A typical slab bridge was analysed using non-linear FE analysis and the structural responses with different reinforcement designs were compared.

2. RESULTS

It was found that unrealistic moment and shear force concentrations emanating from different sources need to be treated differently. Concentrations due to geometrical idealisations can be overcome by using sufficiently dense FE mesh and by using the cross-sectional forces and moments in critical cross-sections. The cross-sectional moments and shear forces in a slab will tend to go to infinity, when the element mesh is being refined, if it is supported in a single point. However, in reality, the largest stresses are obtained in the critical cross-sections around the support or slab-column connection. Moments and shear forces in the critical cross-sections were found to be unaffected by the geometrical simplification if the FE mesh is dense enough. At least two first-order (or one second-order) shell elements are needed between the support or connection point and the critical cross-section. The peak values inside the critical cross-sections do not have any meaningful physical interpretation and can be ignored.

Concentrations of cross-sectional moments and shear forces due to material simplifications, i.e. from the assumption of linear response, need to be redistributed. In particular, the reinforcement moments need to be redistributed in the direction perpendicular to the bars, so that the reinforcement can be arranged in strips with equal bar spacing. What limits a proper strip width is the capacity for plastic rotations in the slab under loading up to failure. However, in the non-linear FE analyses made, no clear relation was found between strip widths and the plastic rotations required. Both the distribution between support and span moments and the overall lateral distribution across the whole slab width had a larger influence than the strip widths. In fact, the design that gave the widest strips resulted in the smallest plastic rotations. For service loads, no difference in crack widths was found between the different reinforcement designs.

When designing a slab bridge, it is recommended to arrange the reinforcement in "column" and "mid" strips, with widths chosen according to recommendations in handbooks. The recommendations given in Vägverket [3] regarding strip widths are likely to be conservative. When assessing an existing slab bridge, redistributions of the reinforcement moments within the slab cross-sections are necessary to avoid excessive under-estimation of the load-carrying capacity. Here, the moment should be redistributed so that the moment distribution corresponds to the available reinforcement in the bridge. The handbook recommendations would here be too rigorous, and should not limit the redistributions. Both in design and assessment, it is important that the cross-sections have sufficient ductility, e.g. according to Eurocode 2 [2]).

3. PROJECT INFORMATION

This study was performed as a part of the Sustainable Bridges project. The work was financed by Vägverket and Chalmers.

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