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SINTEF Building and Infrastructure

COIN – Annual Report 2012

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Summary

The vision of COIN is creation of more attractive concrete buildings and constructions. 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.

The three focus areas are:

- Focus area F1) Environmentally friendly concrete structures
    - Binders with low emission and reduced resource consumption
    - Utilisation of concrete in low energy building concepts
- Focus area F2) Economically competitive construction
    - Robust and highly flowable concrete with controlled surface quality
    - Ductile high tensile strength concrete
    - High quality manufactured sand for concrete
- Focus area F3) Aesthetics & technical performance
    - Crack free concrete structures
    - Reliable design and prolongation of service life
    - Structural performance

2012 was the sixth year of the center. More than 40 various articles and presentations were published in 2012 and one workshop was accomplished. 14 master students completed their degrees within COIN, 2 PhD students achieved their degrees.

The Consortium has a Board of Directors, three Thematic Advisory Committees TACs, a manager and a management group. The centre is located in Trondheim with SINTEF Building and Infrastructure as host institution. The Board has nine members; seven from the industrial partners, one from NTNU and one from SINTEF. All partners are represented in the TACs.

The consortium partners represent the value chain of the business sector; material suppliers, concrete producers, contractors and users. They represent leading multinational companies in the cement and building industry. The partners cooperate through the work in the projects (technical work and joint meetings) and in the TACs.

The accumulated cost in 2012 was 29 million NOK.

"COIN includes most of the industry organized research on concrete. This concentration of resources makes it possible to formulate ambitions and implement activities that each firm does not have the capacity to carry on their own"

Sverre Smeplass
Department manager,
Skanska, Norway

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1 Vision and goal

The vision of COIN is creation of more attractive concrete buildings and constructions. 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.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

Ground limestone, fly ash and clinker – components in cement

2 Research plan

The construction industry is one of Norway’s largest, and concrete is the dominating construction material in buildings and infrastructure. COIN’s research plan is based on the partners' innovation themes as well as the demand from the society. Innovation potential, image and customers needs, productivity, sustainability, environment and high performance concrete for harsh climate are topics addressed. COIN seeks a more fundamental understanding of the mechanisms in order to bring the development a major leap forward.

The status discussed in the original project description is still valid, but COIN has turned more in the direction of reducing CO_2-emissions and saving energy and resources. The latter was a driver when COIN reorganised the research tasks to focus on fewer research topics with more research volume. Both nationally and internationally, COIN's three focus areas (see chapter 3.3) are important drivers for research. The first one focus on developing cements with significantly reduced CO_2 emission under production. The second energy focus resulted in implementation of the topic in an EU-project in which COIN was involved, but which was rejected. The third topic of saving resources is manifested in the research on e.g. aggregates and on securing long service life of structures before they need to be repaired or replaced.

Research methodology

The overall research method, described in the original proposal, is *to achieve practical applications through fundamental understandin*g. The methodologies vary between the research tasks. Firstly, the mechanisms underlying the behaviour of cementing materials are of high chemical and physical complexity and are not yet fully understood. Therefore, there is need for investigations on a nano-/micro-scale level. This includes theoretical studies combined with laboratory investigations. The SINTEF group and NTNU together hold the equipment and laboratory facilities required for advanced materials research ranging from nanometre to meters, as well as for advanced research on structural (reinforced) elements. The results will be verified in test productions and case study constructions by the industry partners.

Secondly, the present research revealed a lack of reliable and relevant test methods to be an obstacle for innovation (e.g. fibre reinforced concrete and utilisation of aggregate resources because of risk of alkali-silica-reactions). Hence, further development of test methods is an activity in some tasks.

Thirdly, the present research revealed a lack of field data to be an obstacle for innovation (e.g. chloride penetration and energy consumption as well as thermal indoor climate connected to the thermal mass concept). Hence, systematisation of field data versus laboratory data is an activity in some tasks.

Reinforcement layout and casting of the beams (left) and MSc-students studying the formation of cracks during a full scale experiment (right)

3 Organisation

3.1 The consortium

COIN has 11 partners: SINTEF Building and Infrastructure is host institution, NTNU is research partner and Kværner, Saint-Gobain Weber, Norcem, Unicon, Skanska, Mapei and Veidekke are industrial partners and Norwegian Public Roads Administration is public partner. Together they represent the whole value chain of the business sector.

The consortium was strengthened in 2012 with Velde joining as subcontractor to Skanska. Velde is engaged in COINs activities within Self compacting concrete and high quality manufactured sand. Other subcontractors are the Finnish company Metso (subcontractor to Norcem), also involved in the project High quality manufactured sand, and Reforceteh (subcontractor to Kværner), which is involved in the work with fiber reinforced concrete.

The consortium has a Board of Directors and three Technical Advisory Committees, a manager and a management group. The centre manager reports to the Board. The Board has nine members; seven from corporate partners, one from NTNU and one from SINTEF.

3.2 The center

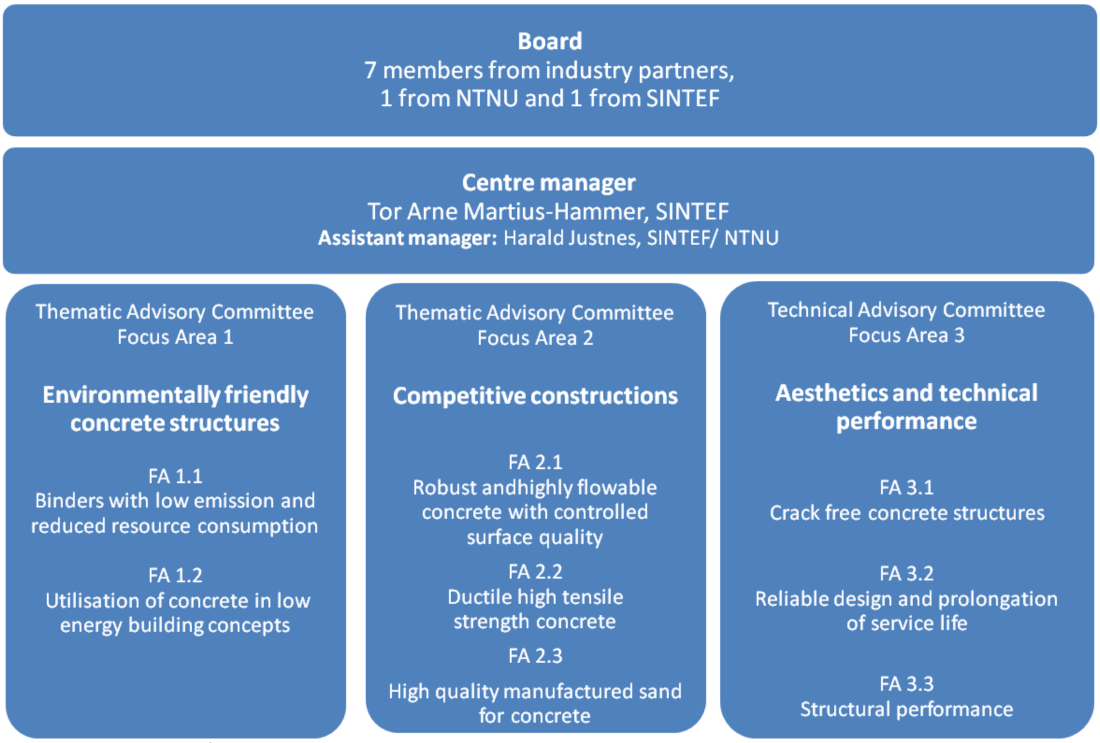
The centre is located in Trondheim with SINTEF Building and Infrastructure as host institution. Senior Scientist Dr Tor Arne Martius-Hammer is Research Centre Manager and Chief Scientist Professor Harald Justnes is Assistant Centre Manager. The SINTEF employed project managers constitute the management group together with center manager and administrative manager.

3.3 Technical activities

The technical activities are organized in 3 focus areas (FA) with 2-3 projects per FA:

- Focus area F1) Environmentally friendly concrete structures
  - Binders with low emission and reduced resource consumption
  - Utilisation of concrete in low energy building concepts
- Focus area F2) Economically competitive construction
  - Robust and highly flowable concrete with controlled surface quality
  - Ductile high tensile strength concrete
  - High quality manufactured sand for concrete
- Focus area F3) Aesthetics & technical performance
  - Crack free concrete structures
  - Reliable design and prolongation of service life
  - Structural performance

Each Focus area has a Thematic Advisory Committee (TAC) with members from the partners. Two of the TACs are headed by the centre manager, whereas Smeplass (Skanska) is the head of the third. The TACs have the responsibility to establish the innovation objectives and criteria, prioritizing and reporting. The TACs also break down the overall objectives into manageable and adequate action plan and tasks.



COIN organisation chart

3.4 Cooperation within the center

The centre operates in close cooperation with NTNU Faculty of Engineering Science and Technology. Three professors at the Department of Structural Engineering (Kanstad, Jacobsen, and Geiker) are disciplinary responsible for six projects. In addition four adjunct professors at NTNU are strongly involved in COIN: Kjellsen (Norcem) is project manager and member of thematic advisory committee, Smeplass (Skanska) is engaged in several projects, member of the board and member of thematic advisory committee and Larsen (Norwegian Public Roads Administration) is also member of a technical advisory committee.

Justnes (SINTEF) is project manager and disciplinary responsible for one project, and adjunct professor at NTNU, Department of Materials Science and Engineering.

The centre uses the laboratory facilities of NTNU and of SINTEF in Trondheim as well as in Oslo. The industrial partners as well as NPRA have research facilities own laboratories, and some of the experiments are also been done in their laboratories, both in Norway and abroad.

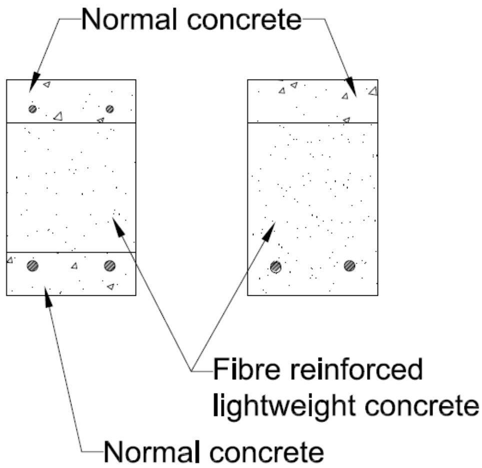
Researchers from all partners are working in COIN projects. Project groups comprise of PhD candidates, researchers from SINTEF, professors at NTNU and personnel from the other partners. The partners cooperate through the work in the projects (technical work and joint projects meetings). The main strategy for knowledge transfer is to have joint activities and to involve many persons from each industry partner. Four partners or more are represented in all projects, four partners have personnel taking part in the Master of Science education at NTNU and one partner is supervising Master students at Oslo University College.

3.5 Cooperation within the center from a PhD candidate's view

Interview with Linn Grepstad Nes

In her PhD study, Linn Grepstad Nes has chosen focus on a concrete element which is composed by layers of different types/ qualities of concrete reinforced with conventional steel bars and/or fibres. The beams studied in this project are beams composed by different layers of concrete either cast wet-on-wet or at different times. Cross-sections of the hybrid concrete beams are shown in the figure below.

Photo: G. Zirgulis



Cross-sections of hybrid beams

The beams consist of two or three layers of normal weight concrete [NC] and fibre reinforced lightweight concrete [FRLWC]. There are two main types, the first type is from the first test program and the testing was conducted in spring 2010. Four beams were subjected to the 4-point bending test, with and without overlay of NC. The second type of beam where tested in autumn 2010 and consists of two layers of concrete. These test programs are the most extensive, including 16 large beams which experienced both moment and shear failures. A study of the FRLWC was also carried out based on small-scale testing – the uniaxial tension test and the 3-point bending test.

The design principle of the beams is very simple. The intention is that the top layer of normal concrete takes care of the compressive stresses, while the tensile stresses is taken care of by conventional reinforcement when the structure is subjected to bending actions.

Concrete casting at Weber's plant: Knowledge transfer NTNU and Weber personnel

In what way (if any) have you cooperated with others in the center?
Most of the specimens and beams were tested were cast at Weber's factory in Lillestrøm. Steinar Seehus and Ove Loraas, who works in the laboratory at NTNU, were in charge of the mixing and casting with help from the workers at the factory. An exchange of knowledge and experience was made during the days of casting. Also, the fibre reinforced lightweight concrete that in is developed by Weber. Other COIN PhD candidates have not been directly involved in my project, but I have had many useful discussions with Håvard Nedrelid, e-mailing with Elena Vidal Sarmiento and Sindre Sandbakk (defended his PhD thesis in 2011) helped me execute the small-scale testing in the lab.

What potential does your work represent for the partners/ industry?
A structural optimisation with respect to weight has been made, using lightweight concrete in combination with normal weight concrete. Situations where such a combination might be suitable are structures with a long span, e.g. bridges and slabs. When the height of the cross-section increases, the self-weight of the structure also increases leading to a need for more reinforcement. This type of hybrid structure utilises the favourable low self-weight of lightweight concrete which results in a reduction of concrete and reinforcement. The project also includes an extensive study of basic material properties of fibre reinforced lightweight concrete. The study revealed that the fibres improve the performance of the lightweight concrete in terms of tensile strength.

Have you been involved in the master program at NTNU, and if yes: In what way?
I have been cooperating with four master students. Two of them were involved in the first test series, and two helped me carry out the last series. I was their supervisor for writing the master thesis and they helped me doing practical work such as building moulds, casting and beam testing.

Which (if any) advantages do you experience by doing your PhD study within COIN?
Being a part of COIN has made it possible for me to carry out a lot of laboratory work without having to worry too much about the financial part of the project. Also, I have had the opportunity to cooperate with Weber benefiting from their expertise and using their factory.

3.6 Industry partner Skanska Norway's involvement in COIN

To illustrate the way industrial partners are involved in COIN, department manager Sverre Smeplass at Skanska has elaborated on their engagement in the center.

Skanska's intention has been to participate in activities in which we already possess significant knowledge, partly to help push forward the research front, partly to improve our own competitive advantage.

Master student Nina Borvik, who's master thesis was about use of low carbon concrete in the prosject Fornebu S in Bærum, Norway

Skanska participate in:

<u>Focus area 2.1 Robust and highly flowable concrete with controlled surface quality.</u>
The development of a classification system and classification tool for concrete surfaces is of particular interest for us, since this will help us in our efforts to reach a common understanding with our clients of what's expected quality of concrete surface.

<u>Focus area 2.3 High quality manufactured sand for concrete.</u>
We consider this to be the future of concrete mix design technology, and we have invited our subcontractor Velde to help develop the understanding of such materials and their potential. Velde possess state of the art material resources and processing equipment for this activity.

FA. 3.1 Crack free concrete structures

Skanska has contributed to the national research expertise in curing technology for more than 30 years, and we consider this to be one of our major competitive advantages in the concrete field. During the COIN program period, low heat concrete has been introduced as a powerful tool to obtain crack free structures, and we are proud to possess first-hand knowledge of these materials and solutions. NTNU, SINTEF and Norcem have been and will be our long term partners in this field.

FA 3.2 Reliable design and prolongation of service life

Skanska participates in national and international research on service life design. Major effort is also put into participation in international standardization on this topic. The ongoing COIN work will be an important basis for the future revision of these standards.

Our goal in all these subprojects is to contribute through active participation, taking leadership on specific research activities.

Skanska has contributed to the education of MSc and PhD students at NTNU through our Adjunct Professor sponsorship for more than 25 years. At the moment Prof. II Sverre Smeplass is the supervisor for 1 PhD student and 2 master students, all involved in COIN activities.

COIN includes most of the industry organized research on concrete. This concentration of resources makes it possible to formulate ambitions and implement activities that each firm does not have the capacity to carry on their own.

4 Scientific activities and results

4.1 PhD degrees

Two of the PhD students defended and achieved their theses in 2012:

4.1.1 Hardening accelerator for fly ash blended cement

Kien Hoang defended his thesis on *"Hardening accelerator for fly ash blended cement"*. Based on his work, Mapei has applied for a patent on an admixture for concrete that will improve the strength of concretes with fly ash (FA). The patent application will be finalized in 2013. These are the main findings of the doctoral work:

Photo: G. Zirgulis

Using fly ash blended cement (OPC-FA) in construction results in benefits in many aspects of technology, environment impact as well as economic efficiency. However, the use of OPC-FA with higher replacement level of OPC by FA is limited by the low rate of reaction at early age of fly ash, particularly at low temperature. The low reactivity leads to low early compressive strength affecting construction productivity.

Hoang tested several chemicals, which potentially can be used to accelerate the early strength development of OPC-FA, both alone and in combination. The European standard EN-934-2 was used to evaluate the effect of the tested chemicals on the strength development. A combination of small dosages (total less than 0.5%) of sodium thiocyanate, diethanolamine and glycerol ("3-component admixture") appeared to be effective in enhancing the early strength of OPC-FA.

The accelerating mechanism of the 3-component admixture on the hydration of OPC-FA was investigated and the results indicate that the admixture accelerates the hydration of OPC, while the pozzolanic reaction of FA is not promoted. In the presence of the 3-component admixture the dissolution of interstitial phases in OPC was increased. Consequently, gypsum was consumed more rapidly, which lead to a more rapid and larger formation of ettringite and hemicarboaluminate in combination wirh calcium carbonate. The formation of hemicarboaluminate resulted in consumption of CH originating from the hydration of silicate phases in OPC. The 3-component admixture also promoted the dissolution of silicate phases leading to an acceleration of the hydration of these phases.

A synergistic effect on the acceleration of the hydration of OPC-FA was observed when applying the 3-component admixture. The sample using the 3-component accelerating admixture lead to a higher rate of cement hydration compared to samples using the chemicals individually. The increase in maximum rate of heat evolution in the sample using the 3-component admixture was higher than the sum of increases in maximum rate of heat evolution released from samples using the three chemicals individually. In addition, the 3-component admixture had an increased accelerating effect on the hydration of the OPC-FA system compared to that of plain OPC at both low and normal curing temperature.

4.1.2 Towards a better understanding of the ultimate behaviour of lightweight aggregate concrete in compression and bending

Photo: G. Zirgulis

Håvard Nedrelid achieved the degree PhD for his work *" Towards a better understanding of the ultimate behaviour of lightweight aggregate concrete in compression and bending"*. The PhD study of Nedrelid, particularly the main hypothesis in the thesis, is used as a starting point in the COIN activity on how to achieve ductility of reinforced LWAC structures, see chapter 4.2.7. The short version of his thesis is as follows:

Ordinary normalweight concrete has a low strength-to-weight ratio compared to steel. This may prevent the use of concrete for the construction of tall buildings, floating structures, longspan bridges, etc. One way of overcoming this problem is by reducing the weight of the concrete by replacing the normal gravel aggregates by lighter types.

Unfortunately, there is a general scepticism regarding the use of lightweight aggregate concrete for structural applications. This concern is attached to the more brittle post-peak material behaviour and smoother crack surfaces of these concretes compared to ordinary gravel concrete. However, in Nedrelid's work, the post-peak material behaviour and the force transfer across cracks are considered to be unimportant regardless of the weight of the concrete.

Nedrelid's working hypothesis has been that the three key material characteristics generally dictating the ultimate response of concrete structures are: the large effect small secondary stresses have on the compressive strength; the abrupt increase of the transverse expansion at a stage close to, but not beyond, the peak stress level; and the rapid unloading of the material beyond the peak stress level. As a consequence of these features, the strength and especially the ductility of structural concrete members depend on local triaxial stress conditions that inevitably develop in the compressive zone just prior to failure rather than stress-redistributions owing to post-peak material characteristics as commonly believed. This hypothesis has previously been used with success to predict and explain the behaviour of normalweight concrete in the ultimate limit state. In this work, it is applied to lightweight aggregate concrete.

In its verification process, results from experimental programs reported in the literature have been carefully examined. In conclusion, the test results seem to support the working hypothesis. A three-dimensional nonlinear finite-element code, with a novel failure criterion accounting for the density of the concrete, was also developed for verification purpose. The results from the analyses demonstrated that structural collapse always occurred before the strength criterion in compression was exceeded anywhere within the structure. Since only the compressive region of the failure envelope varied with the weight of the concrete, there was no effect of reducing the density of the concrete in the analyses. This was in accordance with experiments, where usually no dramatic differences in the strength of the members were observed. The somewhat lower ductility of the members with decreasing density can be explained by a lower degree of stress triaxiality in the compressive zone. This was considered to be a result of the often quite modest transverse expansion of the lightweight aggregate concretes prior to failure. However, since the lack of experimental data led to the assumption that the deformational behaviour was the same as that of their normalweight counterparts, this effect could not be catered for by the analyses.

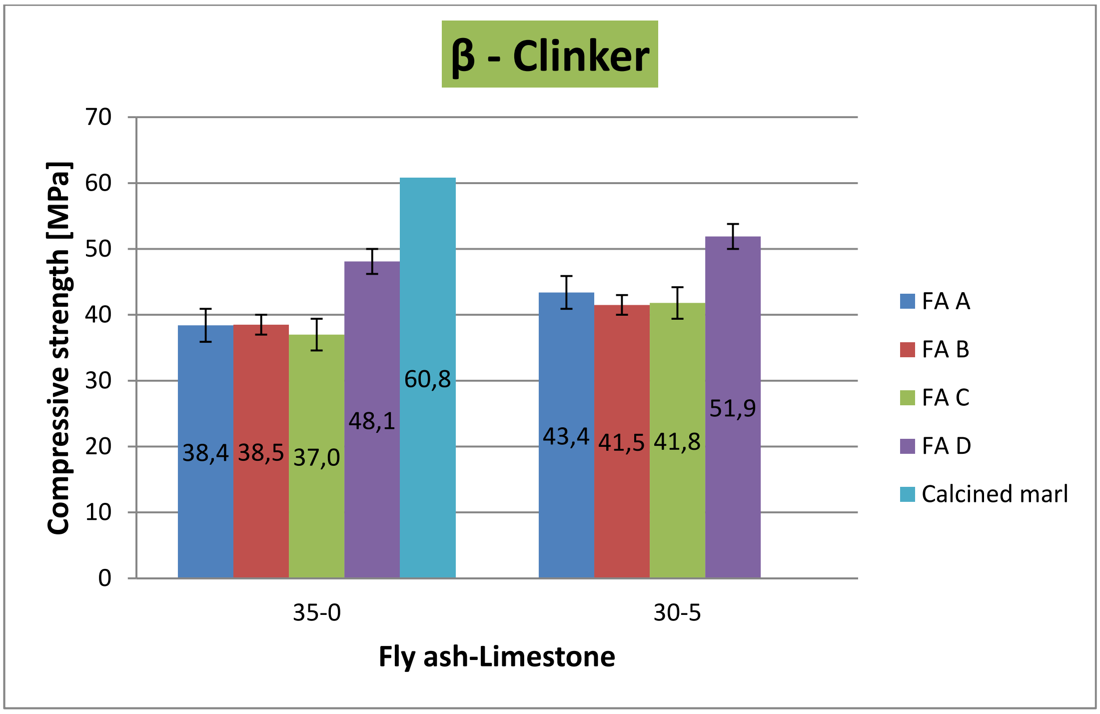
Nonetheless, the theoretical foundation, examination of test results and numerical analyses in this study seem to collectively support the working hypothesis. The research work is therefore considered to contribute to a better understanding of the ultimate behaviour of lightweight aggregate concrete at both the material and the structural level.

4.2 Some research results from the projects 2012

4.2.1 How to make concrete more sustainable

The easiest way of making concrete more sustainable is to either replace clinker in cement, or cement in concrete, with supplementary cementing materials (SCMs) that have a smaller "carbon footprint" than clinker or cement, respectively.

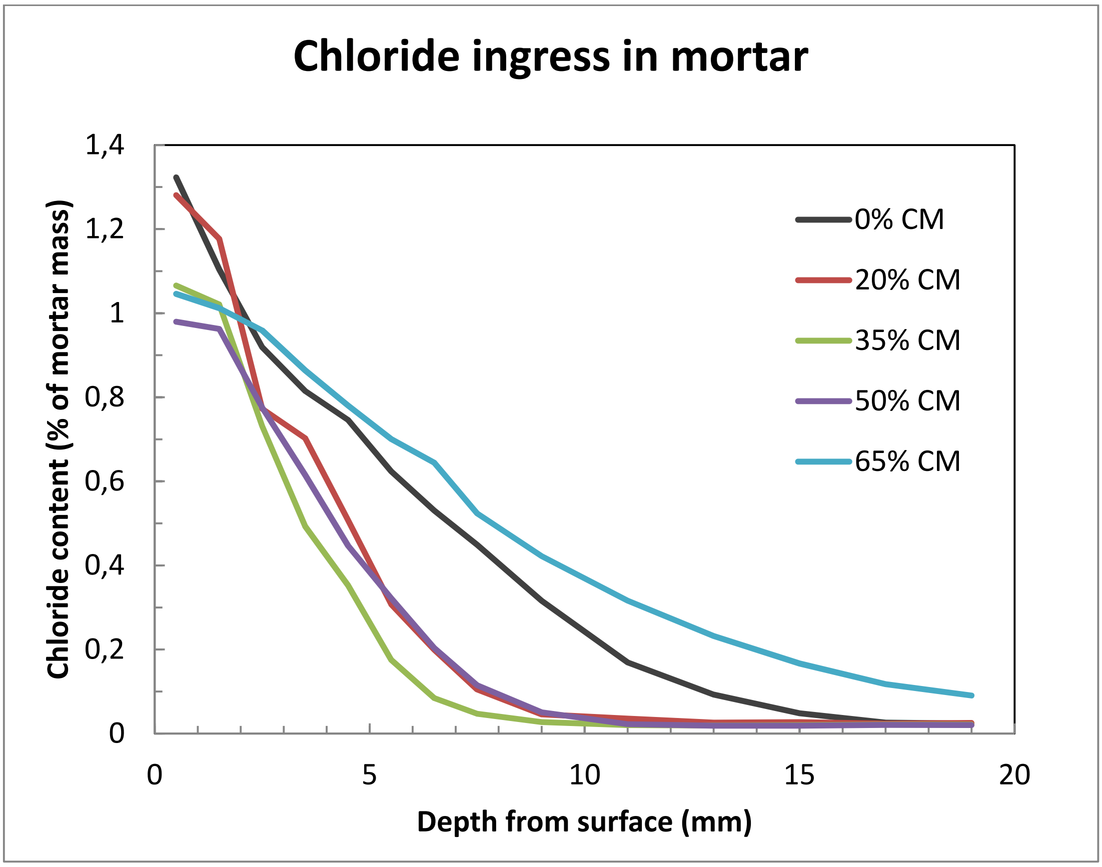
The above concept has been an important part of Focus area 1.1 in COIN from the start. It has been continued in 2012 by testing 4 different clinkers in combination with 4 different fly ashes and limestone in order to further elucidate the synergic reaction between limestone and fly ash in terms of strength. One example is given for clinker β in the figure below showing the 28 days strength for mortar where cement (clinker + gypsum) replaced with 35% fly ash or calcined marl (denoted 35-0) is compared to mortar where cement is replaced by 30% fly ash and 5% limestone filler (denoted 30-5).



The effect of different fly ashes on the compressive strength of clinker β after 28 days curing and their response to combination with lime stone powder. The result is also compared to 35% calcined "marl" replacing the clinker with 3% gypsum.

The results show that the combination of 30% fly ash/5% limestone gives higher strength than 35% fly ash only, meaning that limestone has higher efficiency factor than fly ash in terms of strength. It is also interesting to notice that 35% calcined marl replacement leads to much higher strength than any of the other replacements at 28 days.

Different durability aspects of mortars where cement was replaced with calcined marl up to 65% were also tested in 2012. The most interesting aspect was how calcined marl really lowered the intrusion of chlorides for up to 50% cement replacement as shown in the proceeding figure for chloride penetration profiles. Other aspects measured were capillary suction of water, electrical resistance, sulphate resistance and carbonation resistance. With the exception of carbonation resistance (as for all SCMs), all other durability indicators were improved when calcined marl replaced cement.

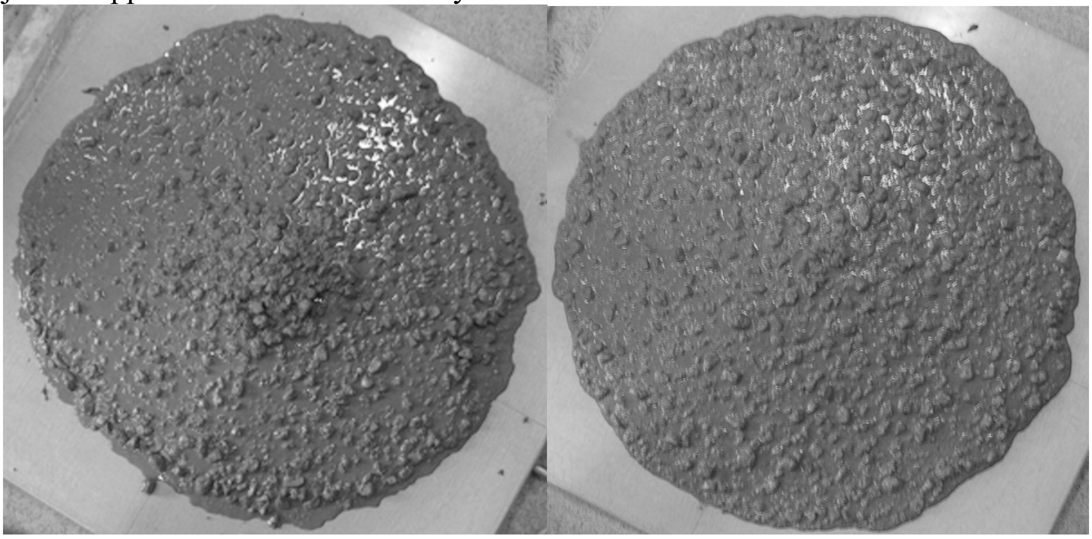


Chloride ingress in mortars where cement is replaced with 0, 20, 35, 50 and 65 vol% calcined marl (CM) after 35 days of exposure to a solution of 165 g NaCl per liter

4.2.2 Segregation resistance of self-compacting concrete

Self-compacting concrete (SCC) is a very fluid concrete which can fill the formwork without external compaction (e.g. poker vibrator). It has been described as one of the most innovative developments in the field of concrete technology as it can lead to improved formwork filling, reduced construction costs and improved work environment.

Unfortunately, SCC cast in-situ in Norway has stagnated at low market share. One reason is low robustness and stability. To this date, the lack of understanding on concrete stability and simple tools for describing stability both for lab and jobsite test are probably the two most important reasons for this situation. Concrete can generally be described as a two phase material comprising particles (coarse aggregates >125µm) and matrix (fluids and particles ≤125 µm). Most attention has been paid to segregation of the coarse aggregate by sinking in the matrix and on visible bleeding. However, the sedimentation and bleeding of matrix itself also need to be understood. One of the main goals of COIN FA2.1 "Robust highly flowable concrete" is to improve understanding on the material factors affecting the stability of both cement matrix and SCC, and then develop simple methods for laboratory and jobsite application to assess stability of concrete.

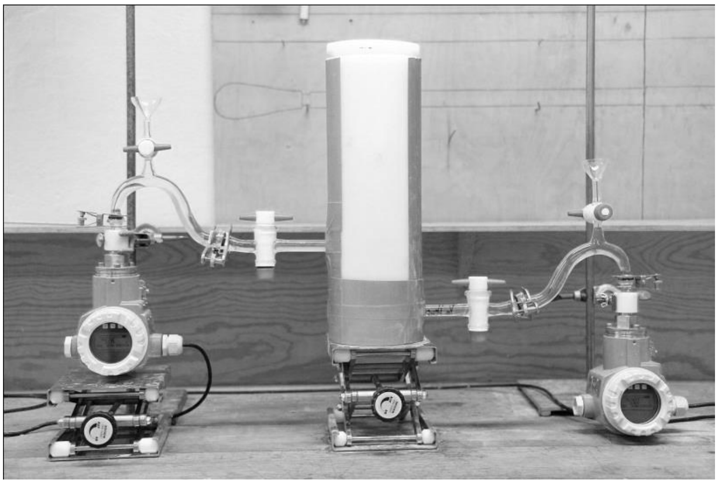


Left: Unstable SCC (aggregate agglomeration in the middle, matrix brim at the periphery) and right: Stable SCC (evenly distributed aggregate, no matrix brim at the periphery)

The project has been focusing on concrete stability investigations from the following three aspects:

- Fundamental stability principles are investigated by the PhD work of Ya Peng. A conceptual model for sedimentation and bleeding is proposed and accordingly a new sedimentation test method for fresh matrix was developed (see the proceeding picture).
- A range of commonly used chemical admixtures, both superplasticizer (SP) and viscosity modifying admixtures (VMA), and different fillers were applied to investigate their influence on the stability. This can contribute to a proper application of chemical admixtures and filler addition regarding stability. Additionally, the research on the stability of the matrix phase is linked to concrete stability studies, in order to establish a better understanding of the relation between paste and concrete stability.
- A simple test method for jobsite application is under developing. The work targets to provide an objective tool to assess fresh concrete stability, to be used in mix design, declaration and control at site.

The need for test methods and a better understanding on concrete stability is not only a challenge for the Norwegian industry. This topic is currently a hotspot for many international associations such as RILEM, fib and ACI. COIN FA2.1 group members are active in technical committees (e.g. RILEM TC 233-FPC) and conferences organized by above mentioned associations.



Left: The test system for sedimentation of matrix (photo by G. Zirgulis)

4.2.3 Ductile high tensile strength concrete (Fibre reinforced concrete)

The objectives are formulated as; (1) To do R&D work which stimulates and makes use of fibres possible in load carrying concrete structures, and (2) Further develop an ordinary concrete with high residual tensile strength, exemplified with target of 15MPa.

Considering the first objective one Achilles heel is the large scatter of the fibre orientation observed in structural elements, and thereby large differences between the tensile strength of standard specimens and structural elements. In 2012 there has been a real breakthrough for the overall understanding of this topic. The good agreement which is achieved between flow simulations carried out in cooperation with DTU, Computer tomography (CT-) scans, image analyses of sawn sections and mechanical testing carried out at NTNU and SINTEF is illustrated in the two following figures. Clearly this indicates that further research with these

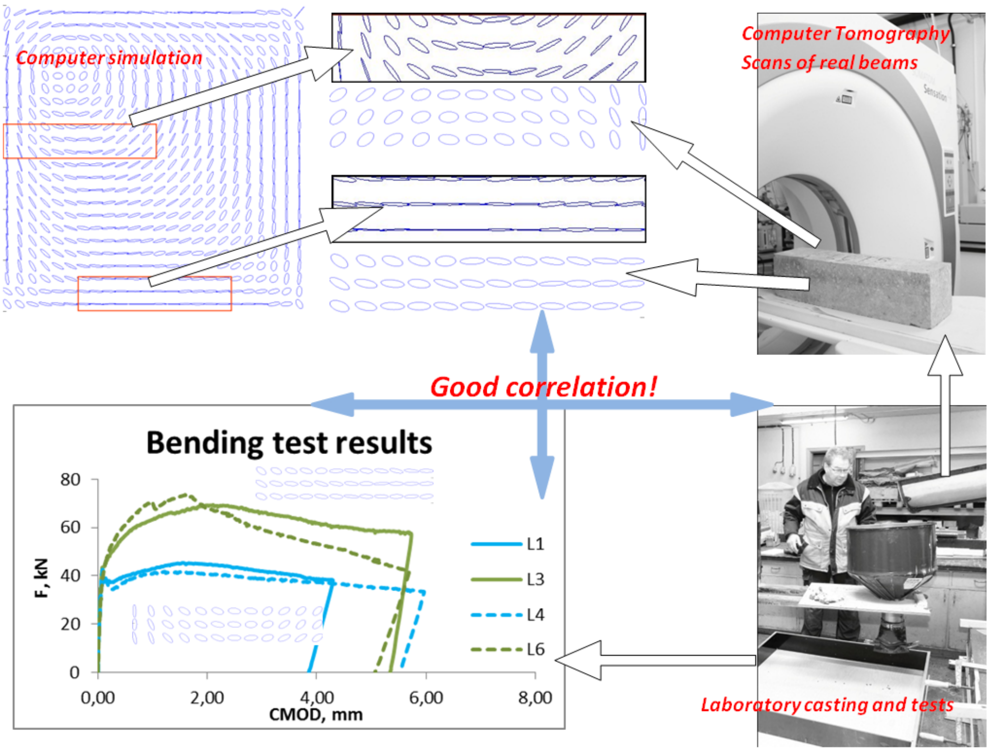
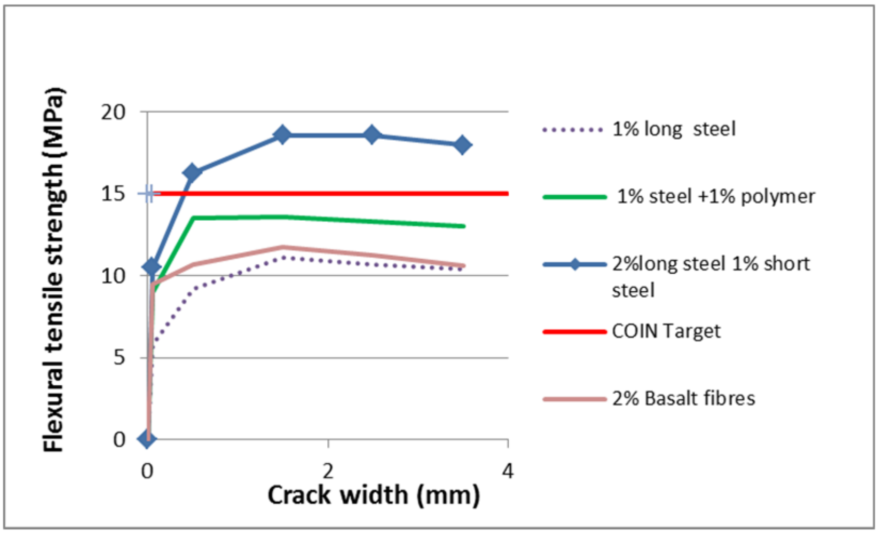


Figure 5 Results from flow simulations of fibre concrete versus CT scanning and mechanical testing

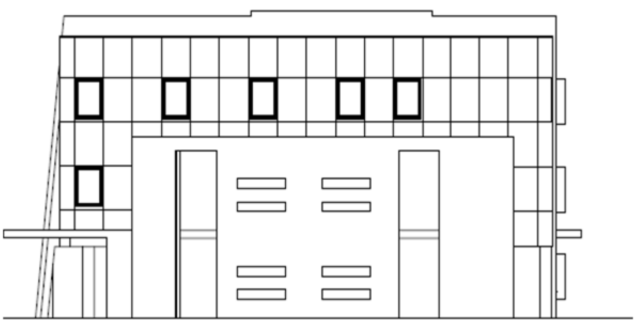
processes will lead to improved practice with safer and more economical use of fibres in general.

Considering the 2nd objective, some of the recent results from the materials development are illustrated in the figure below to give a brief summary of the present status. The achieved performance is gradually improved as the general experience within the research group increases, better proportioning theories are included, and the available fibre types are improved. It is important to note that the relations between results achieved with the different fibre types in the figure must be considered as examples, as no absolute answers for such relations ever will be found.



Selected results from the materials development process

Within the last part of the project; Field and fullscale testing of fibre reinforced concrete structures and the successful use of Basaltic fibres in the façade walls of Veidekke's new office buildings at Rudshøgda (Hamar) should be mentioned (see proceeding sketch and photo). Furthermore, other structural elements as dapped end beams, and beams with circular openings tested for further development of strut and tie models for FRC are explored. These are examples of relatively virgin research topics and an important matter in connection with the ongoing development of design rules.



The façade walls in Veidekkes new office buildings at Rudshøgda are successfully reinforced with Basaltic fibres (Reforcetech's Minibars)

Finally, in 2012 CEN has established a committee to extend Eurocode 2 to include FRC. Standards Norway played an important role in making this decision, and since Focus area 2.2 in COIN is represented in the committee, a golden opportunity has arisen to couple our research experience and the standardization work.

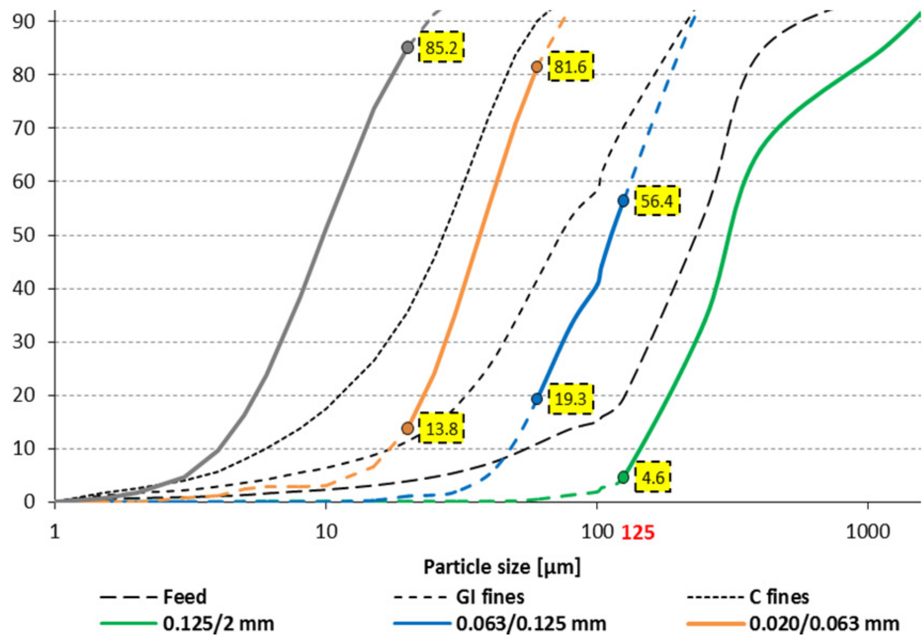
4.2.4 Improving the quality of crushed fine aggregates

The most important outcome from FA 2.3 *High quality manufactured sand for concrete* in 2012 involves launching a comprehensive test program as part of the PhD study carried out in a close co-operation with FA 2.3, towards further development of better crushed fine aggregates (Manufactured sand) for the society. The concept used to design this is based on the conclusions from work carried out within COIN FA 2.3 during the previous years, i.e. that the finest part of the crushed sand should get most of the further research attention. This is due to the fact that by using the right machinery and knowledge one can make the coarsest sand particles with almost the same shape as the natural sand used today as illustrated in the following photo. However, when mixed in concrete, these materials (natural and manufactured sand) would still perform quite differently. Our previous research has proven that this difference mainly arises from the finest (filler) part of the manufactured sand.

Different sand types: (1) High quality 0/8 mm natural sand from Årdal; (2) Low quality 0/8 mm by-product of coarse crushed aggregate production (should not be called manufactured sand); (3) High quality 0/8 mm manufactured sand

The effect of the crushed filler on properties of fresh concrete has not been fully investigated before. This is mainly due to the fact that it is difficult and expensive to get hold of a wide enough range of reference materials (representing different rock types and filler particle size ranges). While another important obstacle is that one needs access to knowledge from a wide range of different industries (such as concrete, aggregate and quarrying machinery production) in order to aim the research towards innovation and thus have a direct industrial outcome, which is readily usable by the society. COIN has in this case served as a source of funding and a hub to facilitate the crucial interaction between the professionals from the aforementioned industries and the academic people (professors, researchers and a PhD student) at NTNU and SINTEF.

In order to proceed with the experiments, a great effort and care have been dedicated to preparation of a set of model-materials (crushed fillers) that represent the complete range of local geological variety. This involved collecting 4/22 mm crushed rock samples from 10 different quarries, which represent virtually all possible rock-types that are used for aggregate production in Norway. Those include: gneiss/ granite, mylonite, limestone, dolomite, basalt, anorthosite, quartzite and aplite. Each sample was of approx. 2 tons in size. This then means a total of 20 tons of 4/22 mm crushed aggregates that have been further processed in a controlled way in the Metso Minerals test plant in Tampere, Finland. Further processing included another step of VSI crushing to generate fines and screening off 0/4 mm crushed sand. Then the 0/4 mm crushed sand material was further split in two different fractions- 2/4 mm and 0/2 mm. Almost 9 tons of the 0/2 mm fractions have been sent to Metso Minerals air-sieving laboratory in Lebanon, Pennsylvania, USA for controlled removal of filler and alteration of filler grading. This means that as much as possible of material below 125 microns shall be removed and further split in fractions 63/125, 20/63 and 0/20 microns. This work is currently in progress; however, some preliminary results are already available, as plotted in the next graph.

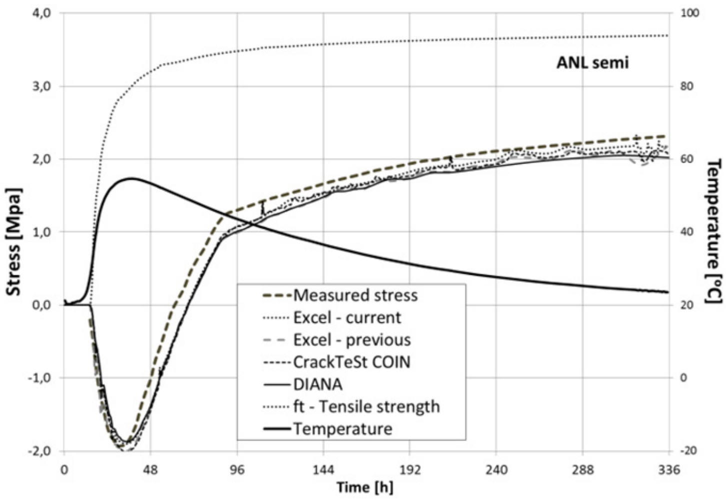


Particle size distributionsof the results from a trial-test completed at the Metso Minerals air-sieving laboratory in Lebanon, PA, USA

The further work in 2013 will involve characterizing the crushed fines with various methods (grading, shape, density, specific surface, porosity, mineralogical composition, z-potential etc.) and testing the prepared materials in filler modified cement pastes (matrices) and subsequently also in full-scale concrete, in order to verify if the found relationships are valid. This will hopefully allow us to carry out a complex and extensive parameter study where different parameters such as grading, specific surface and mineralogy of fines, cement type, admixture and water/ solids ratio of the mixes will be varied. The outcome and goal to reach with the described study is a concept of an industrial and engineered crushed sand production process that is linked to a concrete mix design tool; including a micro-proportioning technology that can exploit the best properties of the crushed fillers and help to adapt these to different types of cement and other binders.

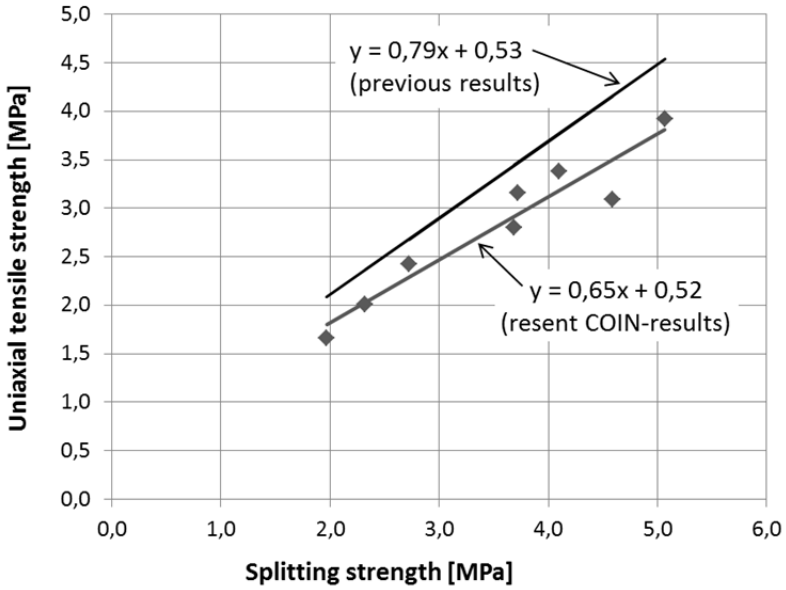
4.2.5 Crack free concrete structures

As for the previous years, the most important results and experience from FA 3.1 in 2012 are from testing of low-heat concretes and the effect of fly ash (FA) content on the time-dependent material property development needed for realistic crack risk assessment at early ages. However, the new special purpose early age concrete calculation program, Crack-TestCOIN, should also be emphasized. A set of verification calculations of the program versus alternative methods have been carried out, and the program is used in the 5th year of NTNU's MSc specialization in Concrete Technology. The program is originally Swedish, but based on initiative and arrangements by COIN, it is now adapted to Norwegian practice and concrete technology. The proceeding figure presents some results from the verification work; Measured stress development from a TSTM-test and calculated 1-dimensional stress by use of various calculation programs. It is worth highlighting that the agreement between the different approaches is very good, and considerably better than previous similar comparisons presented in the literature 5-10 years ago.



Measured stress development from a TSTM-test and calculated 1-dimensional stress by use of various calculation programs

Timedependent development of the following properties has so far been investigated for varying FA-content: Hydration heat, compressive strength, tensile strength, E-modulus, and autogenous shrinkage. In addition theoretical work with material models which describe the material property development has been carried out. This has general interest for both researchers and engineers dealing with crack-risk assessment of hardening concrete structures, but is also important for the material data base of Crack-TestCOIN and other programs systems. One important finding is presented in figure on next page which clearly shows that the time has come to change the relation between uniaxial tensile strength and splitting tensile strength established around year 2000.



Splitting tensile strength-direct tensile strength relations from two test programs, (IPACS 2000 and COIN 2012)as compared to experimental values (♦)

4.2.6 Prediction of reinforcement corrosion in concrete structures

Collaborative projects take place between NTNU, Norcem, SINTEF, Skanska and SVV to establish improved tools for prediction of reinforcement corrosion in concrete structures. Such tools will facilitate the assessment of existing structures and support the design of new reinforced concrete structures.

Much emphasis is placed on means of ensuring a long service life of reinforced concrete structures. Improved durability leads to increased structural reliability, less maintenance and repair, and overall increased sustainability. Possible solutions improving service life and/or sustainability, however, are difficult to evaluate, since current service life models are not based on detailed descriptions of the processes. Collaborative projects take place with the support from COIN to establish improved methods for compliance testing of aggregates for concrete and improved tools for prediction of reinforcement corrosion in concrete structures. Research related to reinforcement corrosion within COIN Focus area 3.2 focus at

- The combined impact of exposure and binder composition on the time dependency of chloride ingress
- The impact of the electrical resistivity of the concrete on the rate of reinforcement corrosion
- The impact of reinforcement corrosion on the structural performance of reinforced concrete structures

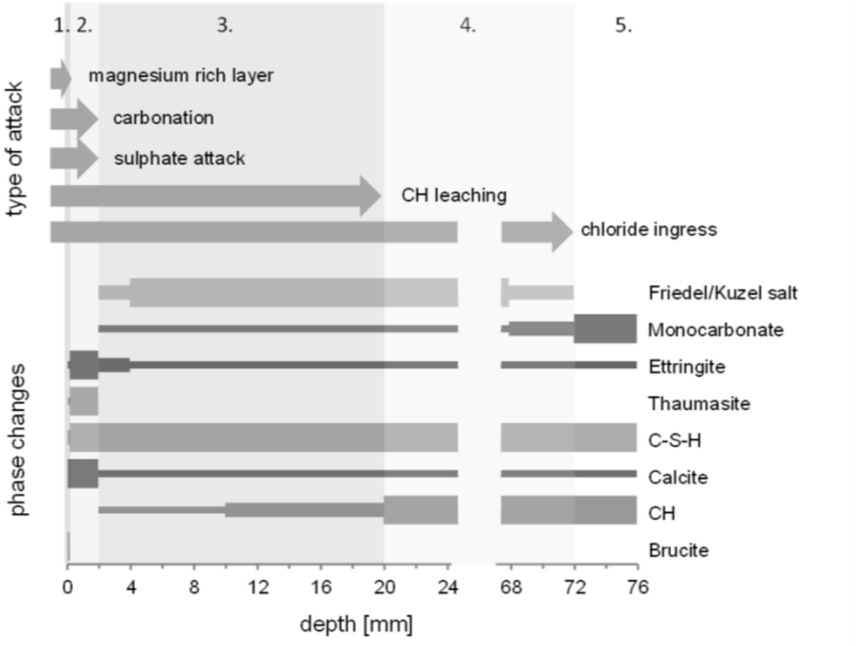
The results, among others, feed into a framework for sustainable infrastructure design being established in collaboration with groups at the Technical University of Denmark (DTU) and Stanford University, USA.

Chloride ingress and phase changes

During 2012 a study of the phase changes in an ordinary concrete standing for 10 years in a tidal zone was finalized (see photo below). Using a range of techniques it was shown that from the exposed surface and inwards different zones had formed. The experimentally observed phase changes generally agreed with the prediction of the thermodynamic model as illustrated in the proceeding phase versus depth illustration.

Studies of phase changes due to ingress and leaching of ions are continued in collaboration with the Norwegian industrial partners and colleagues from DTU, Denmark.

Exposure site in the tidal zone of the Trondheim Fjord (2001). The core was sampled from the bright wall element to the left.

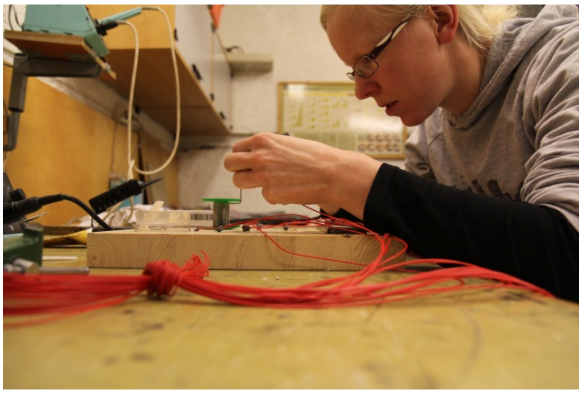


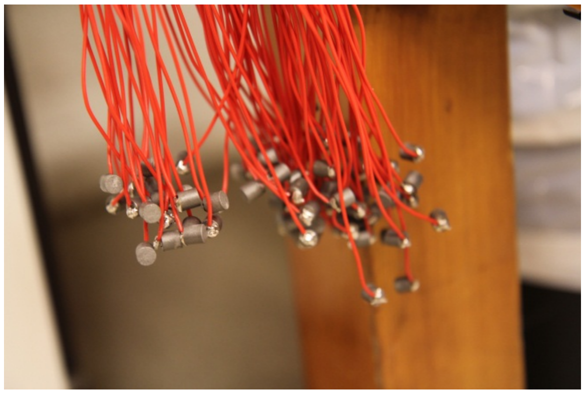
Phase changes observed in a concrete after 10 years exposure to seawater. SEM-EDS analysis of a polished section of the outer surface, showed a Mg rich layer with a thickness of 10-20 µm, as well as the filling of cracks leading from the surface with a Mg rich phase, most likely brucite. In the outermost 2 mm, an increase in the calcium carbonate content was identified by XRD and TGA. In the same zone SEM-EDS analyses indicated enrichment in ettringite. Deeper into the sample, a location dependent variation in the chloride containing alumina phases and the chloride content of the C-S-H was observed by SEM-EDS.

Electrical resistivity as controlling parameter

A literature review on the relationship between concrete resistivity and corrosion rate was finalized in 2012. The process of reinforcement corrosion in concrete is partially controlled by the transport of ions through the concrete microstructure. Ions are charged and the ability of a material to withstand transfer of charge depends upon the electrical resistivity. Thus, a correlation could be expected between the corrosion process of steel embedded in concrete and the electrical resistivity of concrete. There exists an inverse proportional correlation between the parameters. However, the dependency varies between studies of different concretes and one single relationship cannot be established between corrosion rate and conductivity.

Based on the literature review and pilot tests experimental investigating on the rate limiting steps during the early and later stages of reinforcement corrosion (see photos below) have been initiated in collaboration with SVV and colleagues at ETH, Zurich.





Preparing for investigations on the rate limiting steps for reinforcement corrosion

Structural performance of corroded structures

In 2012 work was initiated to develop a finite element methodology for the assessment of the structural performance of corroded RC structures using numerical and analytical simulations and taking into account the spatial variation of corrosion.

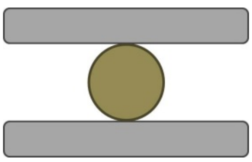
4.2.7 Structural performance

The main objective of the Focus Area 3.3 is to develop and utilize new concrete material combinations and applications. These are some research achievements within the different activities in 2012:

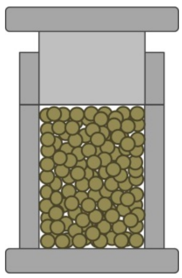
Development of high performance light weight aggregates (LWA)

Different strategies to improve the mechanical properties of lightweight expanded clay aggregates have been tested as part of the PhD work of Markus Bernhardt, and the following three research areas were the main focus in 2012:

Fibre reinforced lightweight aggregates (LWA): Large quantities of fibre reinforced LWA have been produced in a pilot scale rotary kiln. The mechanical properties (strength) of well defined size fractions of the LWA-pellets were tested by two different methods: Single pellets were compressed between parallel platens in the laboratory (left sketch below) while the standard crushing test (right sketch below) was executed according to the European standard. Results showed that the fiber containing material was significantly stronger compared with the non reinforced reference.



Sketch of the single pellet compressing test. A piston pushes down onto the LWA pellet until it cracks.



Sketch of the crushing resistance test where 1 liter of LWA pellets is compressed by 20 mm.

Heat treated LWA: Different heat treatments and cooling procedures were applied to LWA after the normal (standard) laboratory firing process and the resulting material was tested with respect to strength and density. A 60 % strength increase compared with a reference sample was observed after a specific cooling procedure. The mechanisms responsible for the strength increase were the focus of a SEM, XRD and dilatometry investigation during 2012 and revealed properties important for the understanding of stress distribution in the pellets. The concept of toughening by novel heat treatment is currently carried out on an industrial scale and results will be published in 2013.

Improvement of the basic knowledge about LWA: A lot of research has been done in 2012 to understand the strength determining factors as well as the fracture behavior of LWA. A new way to calculate a porosity independent strength for porous, brittle materials has been put forward. The proposed procedure enables the "translation" of results between the two different strength testing methods in the preceding. The developed equations may represent a significant contribution to research related to LWA in the sense that information on the specific strength of the matrix phase is readily obtained by simple strength testing methods and as such also will be a useful tool related to quality assessment of LWA on an industrial scale.

Ice abrasion

PhD Egil Møen focus in his work on developing solutions to handle ice abrasion on offshore concrete structures, and has in 2012 focused on evaluation of experimental results and writing of articles, which will be published in 2013. The industrial partner is Kværner. The performed testing comprise more than 500 hours of ice abrasion testing of various concretes and repair mortars as basis for durability design of offshore concrete structures.

Sakhalin-2: concrete gravity base structure for the offshore platforms

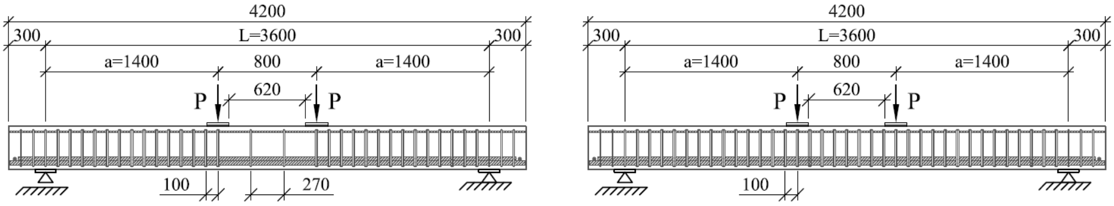
Ductility of reinforced LWAC structures

Finding ways to improve the ductility of LWAC in structural elements has been a subject in COIN since the beginning, and a pilot study was initiated in 2012, with Kværner as the industrial partner. Four MSc-students wrote their thesis related to the experiments in 2012.

Compared to the use of normal density concrete, LWAC in some cases gives considerable more cost effective solutions, e.g. in marine structures. However, the ductility of LWAC, particularly the ability of energy dissipation in structures subjected to seismic action, has been questioned. Information dealing with ductility of over-reinforced LWAC structures in bending or structures subjected to combined bending and membrane actions is limited.

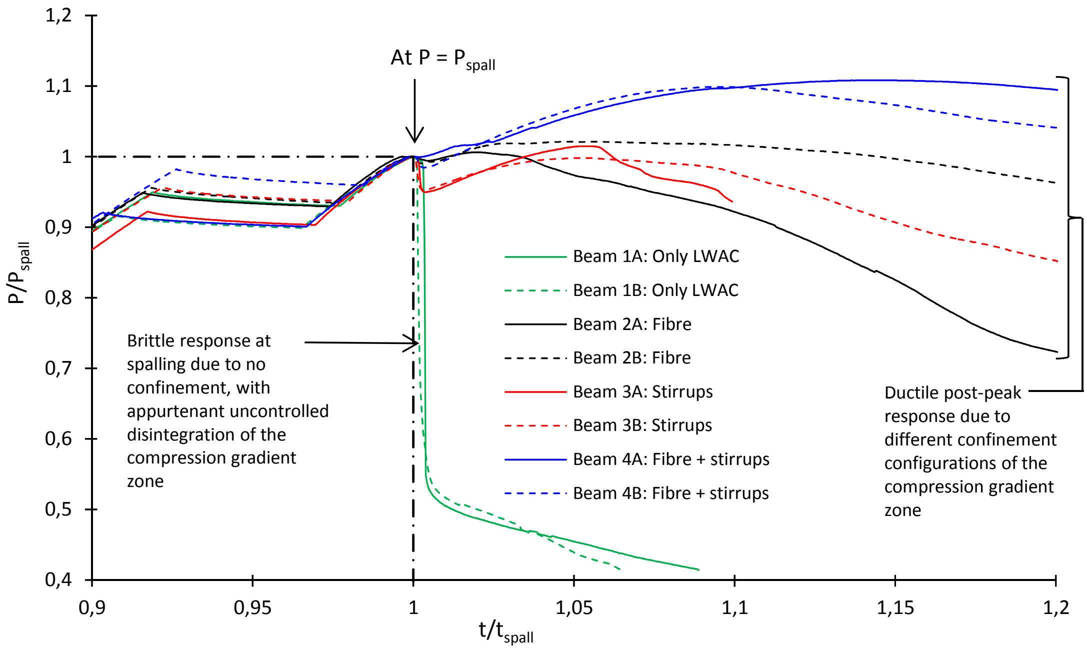
Since the stress-strain characteristics of LWAC in compression play an important part in improving the structural ductility, the main objective in this study was to investigate the passive confinement effect of different configurations in the compression zone in a structure. To study the ductility, eight over-reinforced concrete beams with length 4.2 m and cross-section 0.4 x 0.35 m where subjected to four point bending, as illustrated in the following. Four different configurations of confinement in the compression zone were investigated, only LWAC, steel fibre reinforcement, stirrups, and a combination of steel fibres and stirrups. All beams had the same tensile- and compression reinforcement layout. The LWAC had a mass density around 1800 kg/m^3. The beams were suitable instrumented to measure displacements and strains, and results will be published in 2013.

The different post-peak responses for the beams demonstrate the significant influence of the various confinement configurations on the behavior, e.g. see section of the normalized load-time curves in the plots below. The experiments demonstrated that a reinforced LWAC structure, with proper cross-section design related to the property of the compression zone in bending, may satisfy requests for energy dissipation and controlled behaviour, and even a capacity increase, in the post-peak response. The results are promising, and indicate that LWAC structures (cross-section level) have potential to be compatible with the reliability and performance demands for a structural material, also in structural elements in seismic areas.



Beam 1A and 1B: Only LWAC
Beam 2A and 2B: Steel fibre
Beam 3A and 3B: Stirrups
Beam 4A and 4B: Steel fibre and stirrups

Loading arrangement, confinement configurations and dimensions (in mm)



Section of the normalized load-time curves for all beams around load at spalling, P_{spall}. The beams were loaded at a rate of 1,0 mm/min. P_{spall} in the range 253- 291 kN.

5 International cooperation

5.1 International advisors

As recommended in the midterm evaluation in 2011, COIN has established international advisors. The international advisors' task is to survey the work performed in COIN in order to strengthen its quality. They serve as International Experts in order to support COIN to work with the right topics regarding the need from industry and society and be in line with International state-of-the-art and trends. Overall, they are to ensure that COIN performs high quality research within the field described in the COIN-project.

Thematically, the activities in COIN cover a wide area. The chosen model is thus seven advisors, who together cover the whole range of topics. Our international advisors are:

- Fred Glasser, University of Aberdeen: Focus area 1.1 Binder systems with low emission and reduced energy consumption
- Otto During, CBI: Focus area 1.2 Utilisation of concrete in low enery building concepts
- Olafur Wallevik, ICI Rheocenter: Focus Areas 2.1 Robust highly flowable concrete and 2.3 High quality manufactured sand for concrete
- Steffen Grünewald, TU Delft: Focus area 2.2 Ductile high tensile strength concrete and focus area 3.3 Structural performance
- Jan Erik Jonasson, Luleå TU: Focus area 3.1Crackfree concrete structures
- Mike Thomas, New Brunswick University: Focus area 3.2 Reliable design and prolongation of service life (AAR)
- Bernhard Elsener, ETH: Focus area 3.2 Reliable design and prolongation of service life (chloride corrosion)

5.2 Nanocem

Nanocem is a consortium of 22 academic partners and 11 industry partners from all over Europe, all interested in fundamental research in the nanoscale science of cement and concrete. NTNU is member of Nanocem on behalf of COIN. Professors Justnes and Geiker are our representatives usually attending the two annual meetings, but others may attend depending on the topic.

The PhD study of Jan Lindgård is COIN’s project contribution in the consortium. The study is focusing on developing more reliable AAR concrete prism tests. The work is performed in close co-operation with RILEM TC 219-ACS "Alkali aggregate reactions in Concrete Structures".

5.3 International committees

Both academic employees of SINTEF and NTNU as well as employees of the other COIN partners are members of international committees. In addition to the above mentioned RILEM committee, COIN personnel have been working in several fib and RILEM committees.

5.4 Guest researcher

Alexander Michel, PhD student on leave from DTU, finished his five month employment stay at COIN in February 2012. Michel was working on service life modeling by bringing in a numerical model for prediction of reinforcement corrosion.

5.5 EU-funded projects

5.5.1 Health and corrosion monitoring structural

SINTEF is participating in an EU project headed by Leibniz University Hannover (Prof. Steffen Marx): *Health and corrosion monitoring structural*. The main objective of the project is to continually gather structural information of bridges over a period of two years by means of a monitoring system. Long term data as temperature, humidity, and joint-displacements will be recorded every hour. Short term data influenced by crossing traffic or by wind are observed with a sampling rate of 1000 Hz.

The system is installed on one Norwegian bridge, and the collected information will be used as input in on-going activities within COIN's focus area 3.2 *Reliable design and prolongation of service life.*

5.5.2 STARLIGHT

Focus area 1.2 "Utilisation of concrete in low energy building concepts" is participating in the proposal STARLIGHT: Strong building materials which are self insulating. The application deadline was 4 December 2012. The British engineering company TWI is coordinator.

5.5.3 Infra-heal

COIN through Skanska and SINTEF was involved in the EU-project application Infra-heal initiated by SINTEF Materials and Chemistry. The application made it to second round, but not further.

5.5.4 Nanocilica

A project proposal on Nano-silica from Olivine, initiated by companies in the Netherlands, was turned down in the first round.

6 Recruitment

6.1 Master students

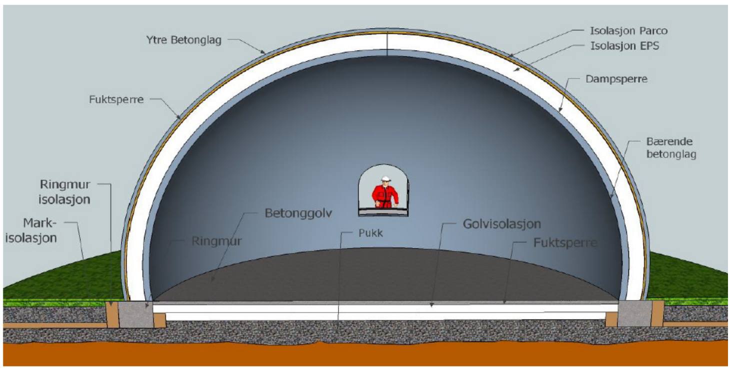
COIN is involved in the education of master of science (MSc) students at the Norwegian education institutions NTNU, UMB and Oslo University College. In 2012 14 students have written eight master theses within the centre. Three master students from foreign institutions have stayed at NTNU to work with their master thesis within COIN. The industrial partners are also involved in supervision of master students.

6.2 Interdisciplinary teamwork in the master programme

All master students at NTNU must during their fourth year of the master programme attend the compulsory course Experts in Teamwork (EiT). This course is meant to provide the students with practical skills in interdisciplinary teamwork. The last few years Department of Structural Engineering has linked its so-called village to COIN. In 2012 Mari Bøhnsdalen Eide (SINTEF) was responsible for village 23: "Concrete Innovation", consisting of 25 students from several disciplines.

The students formed five groups, which looked into various aspects of concrete:

- Group 1 modelled and cast a lightweight fibre-reinforced circular bench in search for an easily transportable bench for the university campus.
- Group 2 explored the concept of underwater buildings.to utilise the coastline and sea level for buildings (left figure below)
- To make concrete a more attractive material for all of us, group 3 developed an app for smartphones that can guide you through several casting procedures for the home market.
- Group 4 explored the concept of building a small concrete hut in the shape of a half-sphere
- The fifth group performed a study to map people's impression of normal concrete surfaces. Based on the results from their survey they tried to create elements that can make concrete surfaces more attractive, see right figure below.



Left: Concept of underwater buildings. Right: Element that can make concrete surfaces more attractive

6.3 PhD candidates

Two PhD students achieved their degrees in 2012 (see chapter 4.1). As the financial period from the Research Council of Norway runs out in 2014, no new candidates have been recruited.

6.4 Post doc

Klaartje De Weerdt was engaged as a Post Doc at NTNU on Improved service life modelling of reinforced concrete structures. The activity focuses on mechanisms and model parameters for the prediction of chloride induced corrosion. The objective of the study is to obtain a better understanding of the underlying mechanisms for changes over time in the surface concentration and diffusion coefficient regarding chloride ingress in concrete from sea water. Visiting MSc student Alessia Colombo has assisted in laboratory testing of chloride binding.

PhD Ueli Angst won German Chemical Society's prize for Best Dissertation 2012. Ueli defended his thesis "Chloride induced reinforcement corrosion in concrete Concept of critical chloride content - methods and mechanisms" as COIN PhD at NTNU in May 2011.

Photo: Ueli Angst flanked by Håvard Nedrelid and Karla Hornbostel.

7 Communication and dissemination activities

7.1 COIN seminar 2012

Once a year COIN organizes a seminar for all personnel involved in the center. The day offers an opportunity to get updated on new results and meet colleagues involved in other COIN projects. The "COIN day" in 2012 was held in Oslo, and more than 40 persons participated.

Thematically the program ranged from Gypsum free cement to nanotechnology for increasing the thermal resistance of concrete. Three PhD students presented some of their work: Karla Hornbostel summed up her literature study of the use of resistivity as indicator of corrosion rate, Markus Bernhardt presented his work with high performance light weight aggregate, and Rolands Cepuritis together with Sverre Smeplass spoke of characterizing functionalities of manufactured sand for fresh concrete properties. The focus area on Crackfree concrete structures exemplified the industry's use of the new knowledge achieved and the focus area on Ductile high strength concrete presented results on the steps towards the objective of an all-round concrete with 15 MPa tensile strength. In addition two of the international advisors, Steffen Grünewald from Technical University Delft and Otto During from CBI, gave presentations.

Photo: G. Zirgulis

7.2 Workshop: Moisture in Concrete

SINTEF and NTNU organized a workshop on moisture in concrete, 6th-7th February 2012 in Trondheim. The workshop was related to and supported by the COIN Focus Areas 3.1 “Crack free concrete structures” and 3.2 “Service life”. The purpose of the workshop was to share information on

- available methods of measuring and modelling moisture in concrete and discuss pros and cons
- moisture induced volume changes

Eighteen persons from Norway, Sweden and Denmark participated in the workshop representing owners, industry, research institutes and universities.

7.3 Scientific publication

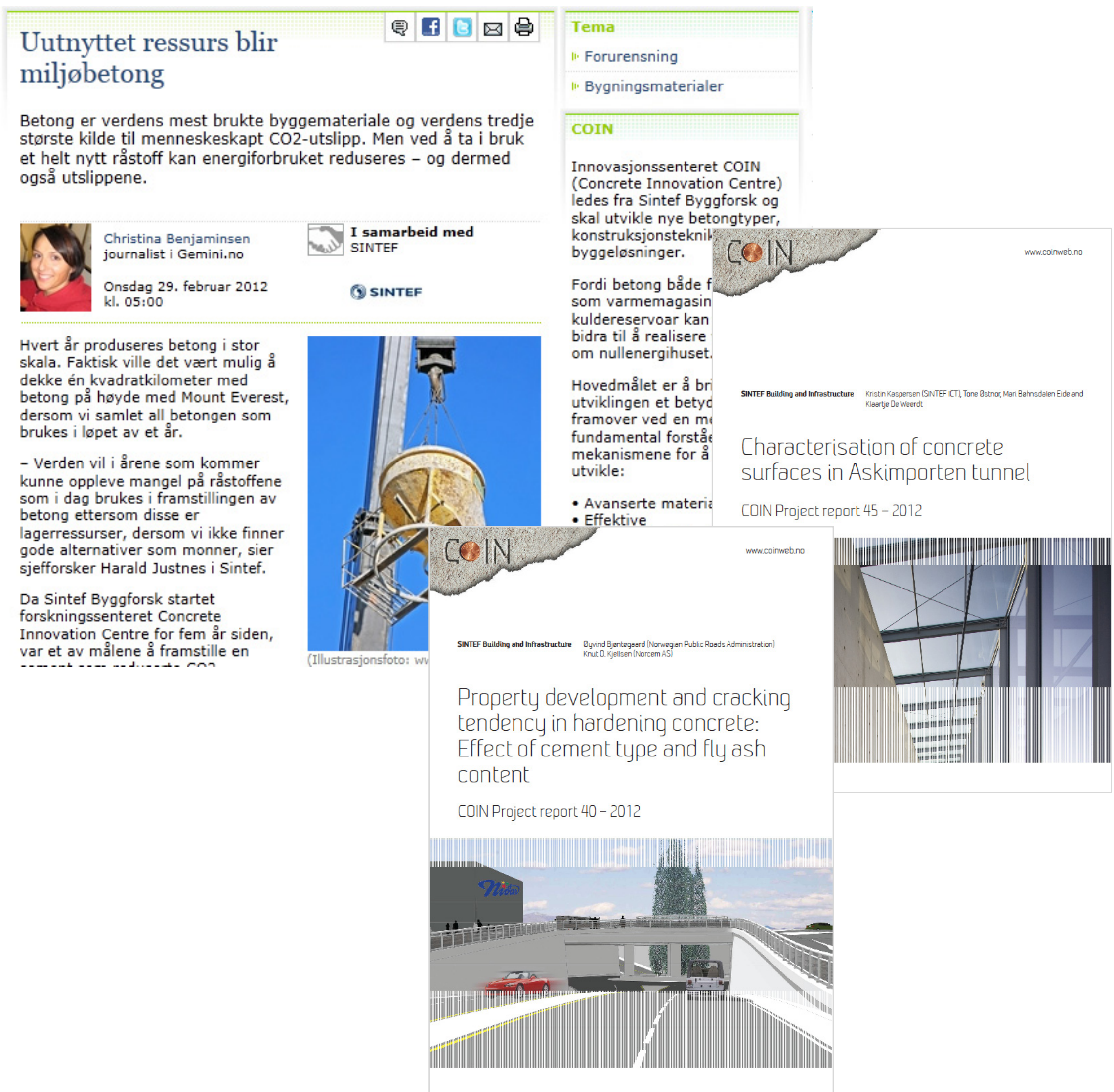
COIN has published more than 30 scientific papers in 2012, including two keynote presentations: One at 2nd international conference on Microstructure related Durability properties of Cementitious Composites, Amsterdam, the Netherlands, and one at 1st International Congress on Durability of Concrete (ICDC), Trondheim, Norway. COIN sponsored the latter conference where COINs assistant center manager Justnes was chairman of the organising committee and several others within the center were organizing the event.

7.4 Dissemination to the industry

COIN puts effort in informing the Norwegian building industry of its research and results. All COIN reports are available for free downloading at the website www.coinweb.no. Tor Arne Martius-Hammer presented "COINs achievements" at the Norwegian Concrete Day, and Klaartje De Weerdt visited a local branch of Norwegian Concrete Association and gave the presentation "What has the industry gained from the COIN programme?" De Weerdt, Mette Geiker and Harald Justnes also gave an invited lecture at Norwegian Public Roads Administration's workshop in February.

7.5 Disssemination to "the rest of the world"

One press release and two articles lead to "COIN record" in popular scientific articles. Media in Norway (and some abroad) reproduced the articles on lightweight aggregated making super strong and light concrete and the potential of marl as an unexploited resource. A press release about Klaartje De Weerdt's PhD work and Low carbon cement with CO_2 emissions reduced by 50 % was also replicated in Norwegian newspapers. De Weerdt was invited in a newstalk in the Norwegian broadcasting radio channel NRK P2.



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COIN Annual accounts 2012

(All figures in 1000 NOK)

Funding

The Research Council	9.500
The Host Institution SINTEF	1.271
Research Partner NTNU	5.926
Kværner Engineering	2.466
Saint-Gobain Weber	2.170
Norcem	3.608
Mapei	1.087
Skanska	804
Norwegian Public Roads Administration	849
Unicon	650
Veidekke	28
Norwegian Concrete Association	250
	28.609

Costs

SINTEF Building and Infrastructure	11.487
NTNU	9.354
Kværner Engineering	2.216
Mapei	937
Norcem	1.893
Saint-Gobain Weber	1.790
Skanska	440
Spenncon	
Norwegian Public Roads Administration	349
Unicon	115
Veidekke	28
	28.609

COIN Personnel 2012

Key personnel

Name	Affiliation	Main research area
Bjøntegaard, Øyvind	NPRA	FA 3.1: Crackfree concrete
Martius-Hammer, Tor Arne	SINTEF	FA 2.1: Robust highly flowable concrete
Kjellmark, Gunrid	SINTEF	FA 3.1: Crackfree concrete
Geiker, Mette	NTNU	FA 1.1 and 3.2
Jacobsen, Stefan	NTNU	FA 2: Improved construction technology
Jensen, Tore Myrland	SINTEF	FA 3.3: Innovative construction concepts
Justnes, Harald	SINTEF	FA 1.1: Advanced materials and admixtures
Kanstad, Terje	NTNU	FA 2.2: Innovative construction concepts
Jelle, Bjørn Petter	SINTEF	FA 1.2: Energy preserving and insulationg concrete
Kjellsen, Knut O.	Norcem	FA 3.1: Crackfree concrete
Smeplass, Sverre	Skanska	FA 2.1, 2.3 and 3.1
Wigum, Børge Johannes	NTNU/ NorStone	FA 2.3: High quality manufactured sand for concrete
De Weerdt	SINTEF	FA 2.1: Improved construction technology
Østnor, Tone Anita	SINTEF	FA 1.1: Low-carbon footprint binders

Visiting Researchers

Name	Affiliation	Nationality	Sex M/F	Topic
Alexander Michel	DTU	German	M	Service life modelling: Prediction of reinforcement corrosion
Madeleine Flint	Stanford University	American	F	Service life modelling: A probabilistic framework for performance-based durability engineering

Postdoctoral researchers with financial support from the Centre budget

Name	Nationality	Period	Sex	Topic
De Weerdt, Klaartje	Belguim	2012-2013	F	Improved service life modelling of reinforced concrete structures

PhD students with financial support from the Centre budget

Name	Nationality	Period	Sex	Topic
Bernhard, Markus	German	2010-2013	M	Development of super LWA
Hoang, Kien	Vietnamese	2009-2012	M	Concrete admixtures
Hornbostel, Karla	German	2009-2013	F	Electrical resistivity
Møen, Egil	Norwegian	2007-2012	M	Ice abrasion
Lindgård, Jan	Norwegian	2007-2011	M	AAR: Lab. testing vs field performance

PhD students working on projects in the centre with financial support from other sources

Name	Funding	Nationality	Period	Sex	Topic
Grepstad, Linn	NTNU	Norwegian	2007-2011	F	Hybrid structures
Klausen, Anja B. E.	NTNU	Norwegian	2009-2013	M	Young concrete
Kioumarsi, Mahdi	Private	Iranian	2011-2015	M	Structural effects on reinforcement corrosion
Zirgulis, Giedrius	NTNU	Lithuanian	2010-2013	F	Fibre concrete
Peng, Ya	NTNU	Chinese	2010-2014	F	Rheology of fresh concrete
Sarmiento, Elena	NTNU	Spanish	2011-2015	F	Flowable/ fibre concrete
Nedreli, Håvard	NTNU	Norwegian	2007-2012	M	LWAC – testing and modelling
Cepuritis, Rolands	Norcem	Latvian	2011-2015	M	Crushed aggregates for concrete

Master degrees

Name	Sex	Topic
Bakken, Lisa	F	Ductilityof lightweight aggregate concrete
Sagosen, Kristine B.	F	Ductility of lightweight aggregate concrete
Lang, Fredrik Tørud	M	Ductility of lightweight aggregate concrete
Rønningen, Øystein	M	Ductility of lightweight aggregate concrete
Øfsdahl, Ellen	F	Fibre-reinforced Self-compacting Concrete - Prediction of Rheological Properties
Skadal, Karsten Lie	M	Basalt Reinforced Concrete in Load Carrying Structures: Structural Behaviour in the Serviceability and Ultimate Limit State
Olimb, Ane Marte	F	Testing of fibre reinforced concrete structures: Shear capacity of beams with openings
Hansen, Siri Weydahl	F	Testing of Fibre Reinforced Concrete Structures: Shear Capacity of Beams with Corbel-End
Nordbrøden, Hanna	F	Testing of Fibre Reinforced Concrete Structures: Shear Capacity of Beams with Corbel-End
Tordal, Kristian Nesse	M	Testing of Fibre Reinforced Concrete Structures: Structural Behaviour in the Serviceability and Ultimate Limit States
Flakk, Øystein	M	Testing of Fibre Reinforced Concrete Structures: Structural Behaviour in the Serviceability and Ultimate Limit States
Knudsen, Eirik	M	Basalt Reinforced Concrete in Load Carrying Structures: Structural Behaviour in the Serviceability and Ultimate Limit State
Høie, Truls Holm	M	Vurdering av basalt- og stålfibres effekt og mekaniske egenskaper i jetpeler
Vermedal, Andreas	M	Vurdering av basalt- og stålfibres effekt og mekaniske egenskaper i jetpeler

COIN Publications 2012

Journal papers

Justnes, Harald: Acceleration by retardation, 4 pages in Cement and its Applications" (in Russian), September-October issue 2012, ISSN 666-9-015-42

Spangenberg, Roussel, Hattel, Sarmiento, Zirgulis, Geiker: Patterns of gravity induced aggregate migration during casting of fluid concrete, pp 1571-1578, Concrete and Concrete Research Vol 42 Dec. 2012, ISSN 0008-8846

Jelle: Traditional, State-of-the-Art and Future Thermal Building Insulation Materials and Solutions - Properties, Requirements and Possibilities, Energy and Buildings, 43, ISSN 2549 2563, 2011

Lindgård, Andiç-Çakır, Fernandes, Rønning, Thomas: Alkali–silica reactions (ASR): Literature review on parameters influencing laboratory performance testing, Cement and Concrete Research, 42 (2012) 223-243

T. Gao, B. P. Jelle, A. Gustavsen, Stefan Jacobsen and Harald Justnes: Aerogel-Incorporated Concrete: An Experimental Study, Submitted for publication in Cement and Concrete Research, 2012

Conference papers

Nes,Linn Grepstad and Øverli, Jan: Presentasjon på BEFIB i Guimaráes, Portugal September 19-21, 2012

Lindgård, Rønning, Thomas: Development on an ASR performance test: Preliminary result from a PhD study, Proceedings of the 14th International Conference on Alkali-Aggregate Reactions in Concrete, Austin, Texas, May, 2012

Peng, Ya and Rudberg, Espen: Presentation at 10th CANMET/ ACI in Prag, Chezh Republic, October 28-31, 2012

Martius-Hammer, Tor Arne and Kanstad, Terje: Presentation at ERMCO in Verona, Italia, June 20-22, 2012

Geiker, Mette: Presentation at International RILEM Workshop on Present and Future Durability Challenges of RC structures, Zürich, Switzerland April 17-18, 2012

Justnes, Geiker: A critical view on service life predictions based on chloride induced corrosion, Keynote, 2nd international conference on Microstructure related Durability properties of Cementitious Composites, Amsterdam, April 11-13, 2012

Flint, Michel, Gussiås, Larsen, Østvik, Billington, Geiker: Overview of US-Norway collaboration on bridge repair sustainability, Proceedings of the 1st International Congress on Durability of Concrete (ICDC), Trondheim, Norway, June 18-21, 2012, ISBN 978-82-8208-031-6

Hornbostel, Larsen, Geiker: Relationship between concrete resistivity and corrosion rate – a literature review, Proceedings of the 1st International Congress on Durability of Concrete (ICDC), Trondheim, Norway, 18-21 June, 2012, ISBN 978-82-8208-031-6

Geiker, Justnes: Prediction of chloride induced corrosion for service life modelling, Keynote, Proceedings of the 1st International Congress on Durability of Concrete (ICDC), Trondheim, Norway, June 18-21, 2012, ISBN 978-82-8208-031-6

Østnor, Justnes, Rudolfsen: Strength development and durability of mortars with calcined marl as supplementary cementing material, Proceedings of the 1st International Congress on Durability of Concrete (ICDC), Trondheim, Norway, June 18-21, 2012, ISBN 978-82-8208-031-6

Østnor, Justnes, Rudolfsen: Strength development and durability of mortars with calcined marl as supplementary cementing material, Proceedings of the 32nd Cement and Concrete Science Conference, Belfast, UK, 17-18 September 2012, 5 pp

Justnes, Østnor, Rudolfsen: Calcined Marl as Alternative Pozzolan, Proceedings of 5th International Conference of Asian Concrete Federation, Chonburi, Thailand, 24-26 October 2012, Paper no. 154, 5 pp

Justnes: Aspects of Gypsum-free Portland Cement, Proceedings of 10th (former CANMET/ACI) International Conference on Superplasticizers and Other Chemical Admixtures in Concrete", Prague, Czech Republic, October 28-31 2012, SP-66, 15 pp

Danner, Østnor, Justnes: Calcined Marl as Pozzolana for Sustainable Development of the Cement and Concrete Industry, Proceedings of the 12th CANMET/ACI International Conference on Recent Advances in Concrete Technology and Sustainability Issues, Prague, Czech Republic, October 30 – November 1, 2012, 12 pp

De Weerdt, Geiker: Changes in the phase assemblage of concrete exposed to seawater - case study, Proceedings of the 1st Conference on Durability of Concrete (ICDC), Trondheim, Norway, June 18-21, 2012, ISBN 978-82-8208-031-6

Lindgård: Development of an ASR performance test - some results from a PhD study, presentation at the RILEM TC 219-ACS seminar/workshop, Izmir, Turkey, 11th October 2012

Jacobsen, Bekker, Uvarova, Pomnikov, Kim, Fosså: Concrete Ice Abrasion: Deterioration Mechanisms, Testing and Modeling, Proceedings ICDC 2012 International Congress on Durability of Concrete Trondheim Norway, June 18-21. ISBN 978-82-8208-031-6

Jacobsen, Kim, Pomnikov: Concrete Destructure due to Ice-Indentation Pore Pressure, Proceedings of the Twenty-second (2012) International Offshore and Polar Engineering Conference. International Society of Offshore & Polar Engineers 2012 ISBN 978-1-880653-94-4, pp 1258-1263

Jacobsen, Ollendorff, Geiker, Tunstall, Scherer: Predicting AEA dosage by Foam Index and adsorption on Fly Ash, Durability Aspects of Fly Ash and Slag in Concrete Workshop Proceedings from a Nordic Mini seminar Oslo - Norway, February 15-16, 2012. Oslo: Nordic Concrete Federation 2012 ISBN 978-82-8208-034-7, pp 103-120

Kim, Jacobsen, Bekker, Fosså: Ice-concrete abrasion study, NORTRIB 2012 - 15th Nordic Symposium on Tribology; 2012-06-12 - 2012-06-15

Nguyen, Jacobsen, Melandsø: Capillary Suction Model as Pipes of Different Sizes: Flow Conditions and Comparison with Experiments, Proceedings ICDC 2012

International Congress on Durability of Concrete Trondheim, June 18-21, 2012, ISBN 978-82-8208-031-6

Peng, Jacobsen, De Weerdt, Pedersen, Marstrander: Overview of Rheological Parameters Affecting Stability of SCC, Tenth International Conference on Superplasticizers and other Chemical Admixtures, Proceedings ACI SP-288, Prague October 2012. American Concrete Institute 2012 ISBN 0-870-31775-X. s. 481-496

Books

Nedrelid, Håvard: Towards a better understanding of the ultimate behaviour of lightweight aggregate concrete in compression and bending, ISBN 978-471-3527-3

Hoang, Kien: Hardening accelerator for fly ash blended cement, ISBN 978-82-471-4064-2

Dissemination amongst the industry

Martius-Hammer, Tor Arne: COIN - hva har vi oppnådd? Presentation at Norwegian Concrete Association Day, Oslo, Norway, October 25, 2012

De Weerdt, Eide, Smeplass, Wirthova: The effect of stabilization with either filler or chemical stabilizer on the surface quality of concrete elements, COIN Report 39 2012, ISBN 978-82-536-1264-5

Bjøntegaard, Kjellsen: Property development and crack tendency i hardening concrete: Effect of cement type and fly ash content, COIN Report 40 2012, ISBN 978-82-536-1279-9

De Weerdt: Hva har bransjen fått ut av COIN-programmet? Presentation at Norwegian Concrete Association meeting in Grimstad, Norway, October 2012

Klaartje De Weerdt and Mette R. Geiker: On the application of thermodynamic modelling for the prediction of the hydrate assemblage formed by blended cements, Proceedings of Nordic Concrete Federation Workshop "Durability aspects of fly ash and slag in concrete", Norw. Public Roads Adm. Oslo, 15th - 16th of February 2012

Popular scientific publications

Ny superlett betong – article based on an interview with Tor Arne Martius-Hammer in Gemini No. 1-2012, ISSN 0802-085X

Supersterk lettvekter –article by Christina Benjaminsen, SINTEF, on forskning.no: http://www.forskning.no/artikler/2012/februar/312909

Publicity in mass media

Sterk og lett – article in Lofotposten 2012-02-12:
http://www.lofotposten.no/bolig/article5923424.ece

Sterk og lett – article in Romerikes blad 2012-02-11:
http://www.rb.no/bolig/article5924227.ece

Ny lettbetong utviklet i Trondheim – article in Betre gardsdrifts internet pages 2012-02-10: http://www.gardsdrift.no/id/52635.0

Sterk og lett – article in Hardanger Folkeblad 2012-02-10: http://www.hardanger-folkeblad.no/bolig/article5922878.ece

Sterk og lett – article in Glåmdalen 2012-02-10: http://www.glomdalen.no/ipad_siste/article5922884.ece

Sterk og lett – article in Arbeidets rett 2012-02-10: http://www.retten.no/bolig/article5922878.ece

Un nouveau béton super léger –article on territorial.fr: http://www.territorial.fr/PAR_TPL_IDENTIFIANT/62677/TPL_CODE/TPL_ACTURES_FICHE/PROV/RSSRESEAU_SIT_TERRITORIAL/PAG_TITLE/Un+nouveau+b%E9ton+super+l%E9ger/302-actu.htm

Press release on De Weerdt's PhD thesis: 50 prosent mindre CO_2-utslipp med lavkarbonsement, 2012-02-02: http://www.sintef.no/Byggforsk/Nyheter/50-prosent-mindre-CO_2-utslipp-med-lavkarbonsement/

Lavkarbonsement – 50% mindre CO_2 – article on Nyhetskanalen Innovasjon og design's internet page 2012-02-11: http://www.innodesign.no/nor/Bygg-Anlegg/Lavkarbonsement-50-mindre-CO_2

Halverer CO_2-utslippet – article on Grønn Byggallianse's internet pages: http://www.byggalliansen.no/nyheter_d.html

50 prosent mindre CO_2-utslipp med lavkarbonsement – article on VVS forum's internet pages:
http://www.vvs-forum.no/index.php?id=5015954&showtipform=1&cat=165391

Halverer CO_2-utslipp med lavkarbonsement – article based on bygg.no: http://www.bygg.no/2012/02/84006.0

Ny sement halverer CO_2-utslipp – article based in Teknamagasinet No 1 2012

Radio interview with Klaartje De Weerdt and Per Brevik, Norcem, in "Ekko – Nyhetsrunden - Klima" – NRK P2 2012-02-22

Uutnyttet ressurs blir miljøbetong – article by Christina Benjaminsen on Marl on forskning.no: http://www.forskning.no/artikler/2012/februar/314728

Skal lage miljøvennlig mur – article on marl in Bergens Tidende 2012-03-10

Uutnyttet ressurs blir miljøbetong :
www.start-siden.net/news.php?news_id=2765734 (and many more based on above articles)

SINTEF Building and Infrastructure is the third largest building research institute in Europe. Our objective is to promote environmentally friendly, cost-effective products and solutions within the built environment. SINTEF Building and Infrastructure is Norway's leading provider of research-based knowledge to the construction sector. Through our activity in research and development, we have established a unique platform for disseminating knowledge throughout a large part of the construction industry.

COIN – Concrete Innovation Center is a Center for Research based Innovation (CRI) initiated by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and constructions. The primary goal is to fulfill this vision by bringing the development a major leap forward by long-term research in close alliances with the industry regarding advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.