

**SINTEF Building and Infrastructure**    Børge J. Wigum (editor)

# Summary report Production of high quality manufactured aggregate for concrete

COIN project report 76 – 2015



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### Summary report

## Production of high quality manufactured aggregate for concrete

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## Preface

This study has been carried out within COIN - Concrete Innovation Centre - 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 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.

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 eight projects in three focus areas:

- Environmentally friendly concrete
- Economically competitive construction
- Aesthetic and technical performance

COIN has presently a budget of NOK 200 mill 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 %).

For more information, see [www.coinweb.no](http://www.coinweb.no)

Tor Arne Hammer  
Centre Manager

## TABLE OF CONTENTS

|          |  |           |
|----------|--|-----------|
| <b>1</b> | <b>INTRODUCTION.....</b>   | <b>6</b>  |
| <b>2</b> | <b>SEMINARS AND WORKSHOPS .....</b>  | <b>7</b>  |
| 2.1      | Manufactured sand – Workshop; Stavanger, Norway, October 30 <sup>th</sup> and 31 <sup>st</sup> 2008 .....  | 7         |
| 2.2      | Nordic Concrete Rheology Workshop & Nordic SCC Net Meeting, 3-4 October 2011, Trondheim .....  | 9         |
| 2.3      | Manufactured sand – Seminar, Stavanger, Norway, October 20 <sup>th</sup> and 21 <sup>st</sup> 2014 .....   | 11        |
| <b>3</b> | <b>MASTER THESIS.....</b>  | <b>13</b> |
| <b>4</b> | <b>STATE-OF-THE-ART REPORTS .....</b>  | <b>15</b> |
| 4.1      | Production and Utilisation of Manufactured Sand .....  | 15        |
| 4.2      | Review report on dry and wet classification of filler materials for concrete.....  | 17        |
| <b>5</b> | <b>VARIOUS COIN REPORTS AND PAPERS .....</b>   | <b>20</b> |
| 5.1      | Classification and Particle Properties of Fine Aggregates (< 63µm) – Applied as concrete aggregate. ....   | 20        |
| 5.2      | Hokksund Quarry – Review of the aggregate production.....  | 21        |
| 5.3      | Manufactured sand in concrete – effect of particle shape on workability.....   | 22        |
| 5.4      | A preliminary study on using manufactured sand from Jelsa Quarry for the production of plastic concrete mixes. ....  | 24        |
| 5.5      | Resource Management and a Best Available Concept for Aggregate Sustainability .....  | 26        |
| 5.6      | Environmental Impact and Sustainability in Aggregate Production and Use .....  | 27        |
| 5.7      | An All-Integrated Concept for Resource Efficient Production and Use of Aggregates. ....  | 28        |
| 5.8      | COIN Project: Towards a Zero-Waste Technology for Concrete Aggregate Production in Norway" .....   | 28        |
| 5.9      | More sustainable resources. (In Norwegian; Mer bærekraftige byggeråstoffer") – Presentation at the NGU-day 2014, Trondheim. ....   | 29        |
| 5.10     | Environmental impact, the future criteria of selecting aggregates (In Norwegian; Miljøbelastning, fremtidens kriterium for tilslagsvalg") – Presentation at the conference; Stein i Vei 2013, Stavanger..... | 30        |
| 5.11     | Filler from crushed aggregate for concrete: Pore structure, specific surface, particle shape and size distribution.....  | 30        |

|          |  |           |
|----------|--|-----------|
| 5.12     | Research project on manufactured sand for concrete. ....   | 31        |
| 5.13     | From manufactured to engineered sand for concrete. ....  | 31        |
| 5.14     | Fra maskinsand til høykvalitets tilslag for betong (engineered sand).<br>(partly in Norwegian).....  | 32        |
| 5.15     | Manufactured sand crushing process parameters: short review and evaluation for<br>sand performance in fresh concrete. ....                               | 32        |
| 5.16     | Visualizing and simulating flow conditions in concrete form filling<br>using pigments.....   | 32        |
| 5.17     | SCC matrix rheology with crushed aggregate fillers: effect of physical and<br>mineralogical properties, replacement, co-polymer type and w/b ratio. .... | 33        |
| 5.18     | Crushed aggregate fines for SCC: specific surface & pore size study.....   | 33        |
| 5.19     | Physical properties of Norwegian mineral fillers investigated by different<br>methods.....   | 34        |
| 5.20     | Rheology of matrix and SCC with different mineral fillers and admixtures.....  | 34        |
| 5.21     | Yield stress and slump-flow of SCC: Short review and application. ....   | 35        |
| 5.22     | Innovation in aggregates for concrete; manufactured sand, lightweight aggregate,<br>alkali-silica reaction. ....   | 35        |
| 5.23     | Effect of aggregate crushing on fresh concrete. ....   | 36        |
| 5.24     | Rheology of matrix with different crushed mineral fillers and admixtures.....  | 36        |
| 5.25     | SCC flow visualization in formfilling with black and grey concrete.....  | 36        |
| 5.26     | Flyplassdekke med maskinsand. Værnes APRON Vest .....  | 37        |
| 5.27     | Mikroproporsjonering med fillere fra Velde: Effekt av sammensetning<br>på matriksens flytmotstand.....   | 38        |
| <b>6</b> | <b>TRADE JOURNALS AND NEWSPAPERS .....</b>   | <b>39</b> |
| 6.1      | Sand from the Rocks.....   | 39        |
| 6.2      | From Stockpile to Sand.....  | 39        |
| 6.3      | New type of crushed sand to replace natural sand in concrete production .....  | 40        |
| 6.4      | Kortreist stein løser knipe. Dagens Næringsliv   fredag 7. november 2014.....  | 41        |
| 6.5      | Characterisation of fillers > 0.125 mm used in Case Study Velde.....   | 42        |
| 6.6      | Characterization of fillers with plasticizers: Zeta Potential measurements .....   | 43        |
| 6.7      | Design of a simple and cost-efficient mixer for matrix rheology testing.....   | 44        |
| <b>7</b> | <b>REFERENCES .....</b>  | <b>45</b> |



## 1 Introduction

At the second year of COIN; in early 2008, the project; “High quality manufactured sand for concrete” was established in Focus Area 2 as project FA 2.3. This project has been chaired by representatives from the aggregate producer NorStone – HeidelbergCement. Bård Pedersen was initially the project leader, replaced by Børge Johannes Wigum from 2011 to the end of the project in 2014.

The main aim of the project has been to develop a technology platform for production and use of high quality manufactured sand that allows for 100 % replacement of the natural sand in concrete mix designs giving concrete properties equal or better than concrete with natural sand. Some of the focus points have been; aggregate production, zero waste aggregate production, manufactured sand characterization methods, sustainability, economy and mix design

Various partners and participants have been involved in this project, including;

- **Norsk Stein** - Aggregate producer (Odd Hotvedt)
- **NorStone** - Aggregate producer (Gaute Veland, Bård Pedersen, Børge Johannes Wigum)
- **Nord-Fosen Pukkverk** – Aggregate producer (John Einar Høvik)
- **Veidekke Industri** - Contractor and aggregate producer (Lillian Uthus Mathisen)
- **SINTEF Byggforsk** - Research institute (Svein Willy Danielsen, Marit Haugen, Klaartje de Weerd, Kari Aslaken Aasly, Tor Arne Martius-Hammer, Serina Ng, Olafur Wallevik)
- **Statens Vegvesen** - Norwegian Public Road Authorities (Bård Pedersen)
- **Mapei** - Admixture producer (Espen Rudberg)
- **Norbetong** - Concrete producer (Ernst Mørtzell)
- **NTNU** - University (Stefan Jacobsen, Ya Peng, Rolands Cepuritis)
- **Norcem** (Rolands Cepuritis)
- **Velde** - Aggregate and concrete producer (Sven-Henrik Norman, Hernan Mujica)
- **Metso Minerals** - Producer of aggregate production equipment (Tero Onnela)
- **Skanska** - Contractor (Sverre Smeplass, Oliver Berget Skjølvik)

The project started with a workshop at Hummeren hotel in Stavanger in 2008, and terminated with a workshop at the same venue in 2014.

This report summarises most of the various activities and deliverables carried out in the project period. A significant amount of the activities have been linked to the on-going PhD. work by Rolands Cepuritis at NTNU, and many of the technical results will be presented in his PhD. thesis, intended to be published at the end of 2015.

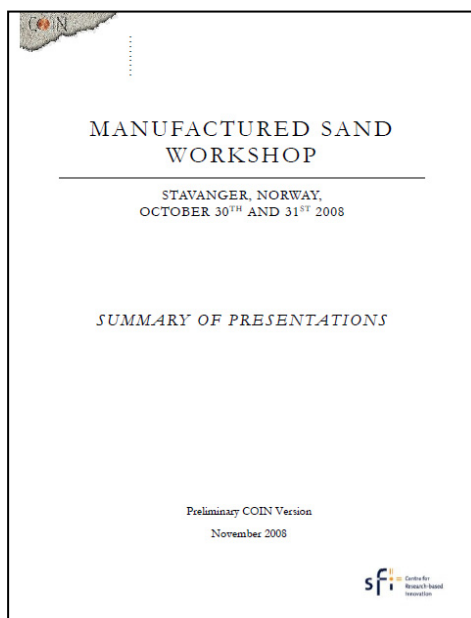
## 2 Seminars and Workshops

### 2.1 Manufactured sand – Workshop; Stavanger, Norway, October 30<sup>th</sup> and 31<sup>st</sup> 2008

As part of the COIN project, an International Workshop on the topic of production and use of manufactured sand aggregates was held at Hummeren hotel in Stavanger, Norway, on October 30<sup>th</sup> and 31<sup>st</sup> 2008<sup>1</sup>. The motivation for the project and hence this workshop was the increasing mismatch between the need for aggregates in the society and the availability of traditionally suitable geologic sources. Thus there was a strong need for developing and implementing technology that can enable the use of alternative resources, reduce the need for transport and present zero waste concepts for the aggregate and concrete industry.

The main aim of this workshop was to create opportunity for professional development, for information sharing and dissemination. We wanted this workshop to be an arena for interactive exchange of experiences between the participants, regarding one of the following topics:

- Sustainability and environmental challenges
- Geological and mineralogical issues
- Production (extraction, crushing, sieving, washing)
- Use of manufactured sand in concrete; mix design
- Characterization and testing of fines
- Standards and specifications
- Alternative utilization of fines
- Case studies.



In total 25 participants from 9 countries participated in the workshop, where a total of 18 lectures were presented. The participations represented various parties of the aggregate business, from production to utilisation, including; geologists, aggregate producers, machinery engineers (producers and users), concrete admixture producers, researchers and concrete producers.

The report from the workshop contains the slides presented at the workshop, including short abstracts for some of the presentations.





**Participants:**

Upper row from left: Sven-Henrik Norman, Jarmo Eloranta, Guðmundur Símonarsson, Chris Rogers, Børge Johannes Wigum, Magnus Evertsson, Per Hedvall, Bjørn Schouenborg.

Lower row from left: Jouni Mähönen, Gaute Veland, Svein Willy Danielsen, Bård Pedersen, Dan Arve Juvik, Odd Hotvedt, Niklas Skoog, Lukasz Debny, Hans-Erik Gram, Makoto Hashimoto, Hugo Pettingell, Jose M. Cuevas, Takato Kaya.

In front from left: Per-Richard Neeb and Roar Nålsund.

Not present: Lillian Uthus Mathisen and Torben Jepsen.

## 2.2 Nordic Concrete Rheology Workshop & Nordic SCC Net Meeting, 3-4 October 2011, Trondheim



SINTEF and NTNU organized a Nordic Concrete Rheology Workshop & Nordic SCC Net Meeting, 3-4 October 2011, Trondheim<sup>2</sup>. A particular section of the Workshop was dedicated to Manufactured sand. Researchers from different Nordic research institutes working on these topics, e.g. CBI (Sweden), DTI (Denmark), ICI (Iceland), NTNU and SINTEF (Norway) were participating. Some major industrial users were also participating, sharing their experiences in the field related to concrete rheology and the use of manufactured sand.

Presentations regarding; “Manufactured sand” at the seminar:

### Monday 3. October

10:30 11:00 Registration

11:00 11:30 Welcome speech - COIN

Bård Pedersen SW SINTEF  
Tor Arne M. Hammer SINTEF  
Klaartje De Weerd

11:30 12:15 LUNCH

#### MANUFACTURED SAND

12:15 12:30 Manufactured aggregates for concrete – why, where and how?

Svein Willy Danielsen SINTEF

12:30 12:45 Manufactured sand in concrete. Practical experiences from aggregate and sand production and concrete mix design.

Sven-Henrik Norman Velde AS

12:45 13:00 Filler and filler quality of crushed rocks in concrete production

Björn Lagerblad CBI

13:00 13:45 DISCUSSION MANUFACTURED SAND + COFFEE

Børge Wigum NTNU/ NorStone

13:45 14:00 Creating a manufactured sand - Factors to consider and methods of processing

Tero Onnela Metso

14:00 14:15 Effect of aggregate crushing on fresh concrete

Rolands Cepuritis NTNU

14:15 14:45 DISCUSSION MANUFACTURED SAND + COFFEE

Bård Pedersen SW



**Participants at the 2.2 Nordic Concrete Rheology Workshop & Nordic SCC Net Meeting, 3-4 October 2011, Trondheim**

Sven-Henrik Norman Velde AS Norway

Reidar Velde Velde AS Norway

Tero Onnela Metso Finland

Øystein Mortensvik Rescon Mapei Norway

Espen Rudberg Rescon Mapei Norway

Bård Pedersen SVV Norway

Lars Busterud BASF Norway

Sverre Smeplass Skanska Norway

Knut Kjellsen Norcem Norway

Ernst Mortsell Norbetong Norway

Nikola Mikanovic HTC Germany

Øyvind Sater Unicon Norway

Eivind Heimdal Unicon Norway

Poul Licht Omya Danmark

Christine Hauck Veidekke Norway

Bernt Kristiansen AF Norway

Mette Geiker NTNU/ DTU Norway/ Denmark

Børge Johannes Wigum NTNU/Norstone Norway

Ya Peng NTNU Norway

Rolands Cepuritis NTNU Norway

Tor Arne Martius Hammer SINTEF Norway

Klaartje De Weerd SINTEF Norway

Svein Willy Danielsen SINTEF Norway

Mari Bohnsdalen Eide SINTEF Norway

Peter Billberg CBI Sweden

Bjorn Lagerblad CBI Sweden

Peter Simonsson LTU Sweden

Jon Elvar Wallevik NMI Iceland

Olafur Wallevik NMI Iceland

Jon Spangenberg DTU Denmark

Jan Skocek DTU Denmark

Claus Pade DTI Denmark



Stefan Jacobsen NTNU Norway

Lars Nyholm Thrane DTI Denmark

### 2.3 Manufactured sand – Seminar, Stavanger, Norway, October 20th and 21st 2014

As a closure of the COIN project 2.3 on manufactured sand, a lunch to lunch seminar was arranged at Hummeren hotel in Stavanger, October 20<sup>th</sup> and 21<sup>st</sup> 2014<sup>3</sup>.

A total of 13 presentations were presented including aggregate production, case studies, classification of fines, mix design and sustainability issues. Excursion site visit was carried out to the production plant of the aggregate producer Velde. A total of 23 persons participated at the seminar.

#### Program of the seminar

| Monday 20 <sup>th</sup> October   | Tuesday 21 <sup>st</sup> October   |
|---|--|
| 12:00 - 13:00<br><b>Lunch</b>   | <b>3. Session - Classification of fines – standardization concrete mix design</b><br>Chair: <i>Børge Johannes Wigum</i>  |
| <b>1. Session - Crushing and screening of manufactured sand</b><br>Chair: <i>Børge Johannes Wigum</i>   | 08:40 - 09:00<br><b>Sverre Smeplass, Skanska:</b><br>Filler composition, a new tool to control concrete workability  |
| 13:00 - 13:10<br><b>Børge Johannes Wigum, NTNU/Norcem</b> : Introduction  | 09:00 - 09:20<br><b>Hans-Erik Gram, Cementsa:</b><br>Sustainable production of fine particles from rock materials – a 2 year project in Sweden   |
| 13:10 - 13:30<br><b>Rolands Cepuritis, NTNU/Norcem</b> :<br>"Engineered sand production with Vertical Shaft Impact (VSI) crushers and static air-classifiers".        | 09:20 - 09:40<br><b>Rolands Cepuritis, NTNU/Norcem</b> :<br>"Methods for characterization of crushed filler properties and principles of proportioning concrete with these materials". |
| 13:50 - 14:10<br><b>Sven-Henrik Norman, Sandvik:</b><br>Manufactured sand solutions by Sandvik  | 09:40 - 10:00<br><b>Hans-Erik Gram, Cementsa:</b><br>How to determine the influence of aggregate fillers on the yield stress and plastic viscosity of micromortar.                     |
| 14:10 - 14:30<br><b>Coffee/discussion</b>   | 10:00 - 10:30<br><b>Coffee/discussion</b>  |
| <b>2. Session - Real cases</b><br>Chair: <i>Svein-Willy Danielsen</i>   | <b>4. Session - Resources – Environmental issues – The future</b><br>Chair: <i>Svein-Willy Danielsen</i>   |
| 14:30 - 14:50<br><b>Odd Hotvedt, Norsk Stein, Jelsa:</b><br>Yearly production of 10 mill. tons aggregate. Challenges and possibilities regarding the sand production. | 10:30 - 10:50<br><b>Bård Dagestad, NorStone:</b><br>Sustainable concrete aggregate in perspective of the resources situation.  |
| 14:50 - 15:10<br><b>Eoin Heron, CDE Global Limited</b> :<br>Washing Manufactured Sands.   | 10:50 - 11:10<br><b>Rolv Dahl, NGU:</b><br>Current and future consumption and supply of building materials in Norway.  |
| 15:10 - 15:30<br><b>Egil Velde, Velde Pukk</b> :<br>An integrated concept of aggregate production and use.  | 11:10 - 11:30<br><b>Olav Hallset, Norwegian Mineral Industry</b> :<br>Public Management of Geological Resources  |
| 15:30 - 18:00<br><b>Excursion to Velde</b>  | 11:30 - 12:00<br>Summary and discussion  |
| 19:00<br><b>Dinner</b>  | 12:00 - 13:00<br><b>Lunch</b>  |



**Participants:**

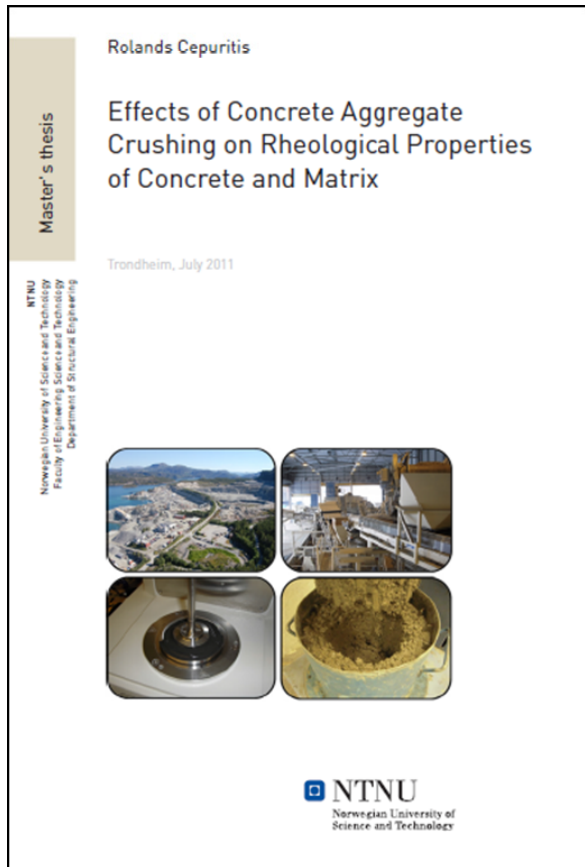
**Front row from left:** Børge Johannes Wigum, Hernan Mujica, Sven-Henrik Norman, Berit Laanke

**Second row, from left:** Stefan Jacobsen, Espen Rudberg, Sverre Smepllass, Svein Willy Danielsen, Rolv Magne Dahl, Knut Li

**Back row:** Bård Dagestad, Reidar Velde, Odd Hotvedt, Marit Haugen, Rolands Cepuritis, Hans-Erik Gram, Oliver Patsch, Egil Velde, Serina Ng, Eoin Heron, Olav Hallset

**Not present:** Brynjar Lund-Andersen & Lillian Uthus Mathisen

### 3 Master thesis



In his Master's thesis, Cepuritis (2011)<sup>4</sup> analysed the performance of manufactured fine aggregate, in concrete, produced by different crushing processes and containing normalized amount of fines. VSI crushing experiments with varying tip (rotor) speeds and further 0/2 mm crushed sand product testing in concrete and filler modified paste with respect to rheological properties have been carried out. The results have been compared to performance of 0/2 mm cone crushed manufactured fine aggregate and partly natural reference sand that are available as commercial products. The effect of the crushed filler on both fresh and hardened concrete properties has also been studied by replacing the initial crushed fines with reference limestone filler. The fines or filler within this study are defined as all aggregate particles passing the 125 microns sieve.

In addition, characterization of all the fine aggregates with different methods was performed with a goal to investigate which of the fundamental rheological parameters of concrete correlate with crushed aggregate properties like filler type, particle size distribution, flakiness index, specific surface area, loose and compacted packing, flow time (rheology) in New Zealand flow-cone etc., to verify which one of the methods is the best to apply.

Proportioning of the concrete mixes has been done following the Particle-Matrix model with strict control of particle size distribution and volume fractions of particles and matrix. Some of the results have been analysed in the light of de Larrard's Compressible Packing Model.

The main results indicate that it is possible to measure changes in concrete rheological properties if manufactured fine 0/2 mm aggregate produced by different crushing processes and containing normalized amount of fines are compared in concrete. Workability increase due to replacement of a cone crusher with a VSI for the last crushing step seems to be of a higher order than changes due to VSI tip speed. Those factors were found to have no measurable effect on rheological properties of the corresponding matrices.

It was found that most of the conventional fine aggregate characterization parameters can give an indication of the 0/2 mm crushed sand performance in concrete with respect to rheology. However, order of relation is rather limited and none of them can be used as a fundamental parameter. Loose and compacted packing measurements tend to show the best correlation. However, the correlation is not satisfying, and, based on the results



acquired within the thesis, two other parameters by combining packing and specific surface concepts have been proposed.

Particle size distribution of crushed sand was found to be a more important parameter that affects the rheological properties of fresh concrete than the crusher type for the last step, the VSI tip speed or filler type and properties.

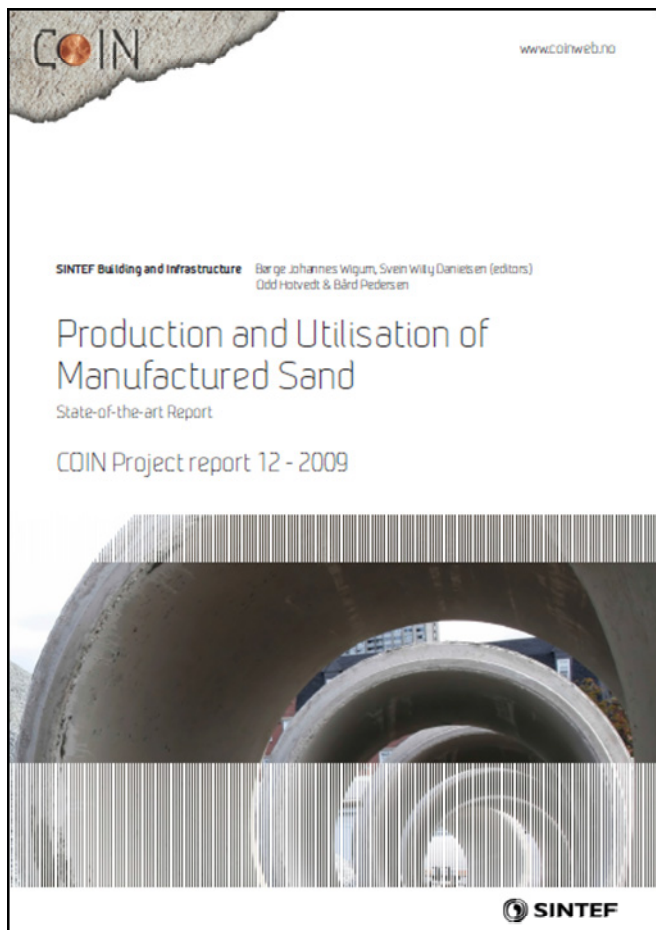
The hardened concrete testing results indicate that filler properties are very essential not only for fresh concrete rheology but also with the respect to mechanical properties of the hardened state.

In this thesis an attempt has been made to incorporate both aggregate crushing and end product consumer process (concrete production) together and thus rank from a wider perspective. Although this study has been reasonably extensive within the scope, it is still considered to be only a basis for further research and development. Clear future research needs have also been clarified.

The Master's thesis is intended to be used for both – quarrying and concrete industry people, the reason why it was the goal to keep it as simple as possible and explain terms that could be unclear for both of the parties.

## 4 State-of-the-art Reports

### 4.1 Production and Utilisation of Manufactured Sand



This State-of-the-art report<sup>5</sup> has been compiled through extensive search of relevant literature and through information and experience provided by international experts. The report deals with the production and use of manufactured sand, which is defined as aggregate material less than 4 mm, processed from crushed rock or gravel, intended for construction use. The motivation for this project is the increased mismatch between the need for aggregates in the society and the need to develop concept solutions for the use of manufactured sand as concrete aggregate.

The intention of this project has been a holistic approach, looking into the whole concept including; environmental issues, mineral properties, sampling and testing, production processes, specifications and new

development in concrete mix design involving the latest generation of admixtures.

#### Environmental issues

Aggregate production is, by the strictest definition, non-sustainable, because aggregate resources are non-renewable. However, sustainability could be achieved by optimizing the whole production process, leading to a maximum of added value for the society, without causing a need for re-deposition or pollution. The real challenge will be to merge the environmental issues with the industrial ones; to create industrial plants, which are at the same time environmentally friendly and economically profitable, which integrate quarrying and industrial production, and finally – for which there exist plans for restoration and area use after completed quarrying period. As natural aggregate resources near urban centres terminate, the transport distances increase. This is already the situation in urban areas in Norway. Even though production of manufactured sand requires more energy than

corresponding production of natural sand, the vicinity to the market, with less transport, will make manufactured sand environmentally favourable.

### **Mineralogical properties – sampling and testing**

When producing manufactured sand, it is possible to select the raw material, i.e. the parent rock. Properties of the parent rock are determined by various petrologic parameters that have an important influence, both upon the blasting and crushing of manufactured sand, e.g. energy consumption, fines production and shape, but also upon the quality of fresh and hardened concrete. In order to tailor the end product for specific purposes, it is important to know how these properties are influencing the end product. It is e.g. experienced that lithology has not so much impact on geometric properties for the sand fraction, i.e. 63  $\mu\text{m}$  - 4 mm; however it may govern these properties for the fines. The effects of secondary minerals on properties and quality of the fines, for use in concrete, are only partly known. This needs to be examined further. A variety of test methods exist, but the industry requires development of sufficient and accurate test methods for fine aggregate. It is in particular important to examine the interaction of properties of fines and the effects of the new generation of concrete admixtures. In addition, it is necessary to define procedures for sampling, handling and testing for quality control purposes to ensure that the “right” material is being tested. Accurate classification of manufactured sand, including fines, will assist the whole industry to e.g. select proper raw material, suitable production equipment and suitable concrete mix design procedures.

### **Production processes**

In order to reach a high-quality final result, each crushing stage needs to be optimized – it is not a good approach to try to repair an insignificantly crushed product by the final crushing stage alone. The installation of Vertical Shaft Impactors (VSI) has proved to be an effective way of producing cubical (even rounded) particles in the small and medium size fractions (< approx. 5 mm). It is, however, a challenge to avoid generating of high amount of fines. The latest generation of dry screening equipment combined with the latest development of air classification have, however, enabled to govern the grading curve very precisely, including the finest part. Configurations of machinery from e.g. Metso/Buell or the V7 concept from Kemco in Japan are good examples, where manufactured sand has been produced for 100% use in concrete. However, it is important to realise that high quality aggregates could be degraded by insufficient procedures of handling and storage.

### **Specifications**

Current specifications in many countries still are based on the use of natural sands, where several specifications do not allow high percentages of fines to be used in concrete. A new understanding of the properties of manufactured sand, and the need to treat it differently is required.

### **Application in concrete – Design of concrete mixes**

The difference in shape properties and particle surface texture indicates that natural and manufactured sands are two different types of material and must be treated accordingly. These facts require development of new concrete mix designs, and knowledge for the application of this material. Experiences of traditional concrete mix design based on natural sand should not be automatically transferred into this new material. The R&D and tradition of using manufactured sand in concrete has been driven by need in different countries. This

implicates that the practice differs in various parts of the world. Japan is an example of a country that early started developing and applying new technologies, since their natural sand resources got depleted many years ago. On the opposite side, North American – especially Canadian – resource conditions have been (and still are) of an order that do not call for alternatives to glaciofluvial sand/gravel as aggregate. In other countries, such as Australia, manufactured sand is seen as an appropriate substitute for natural sand, but it is claimed that it appears difficult to only depend on 100% manufactured sand. In Norway manufactured sand has both been applied in blends with natural sand and as 100% fine aggregate. It must be our ambition for the future to enable 100% use of manufactured aggregate in concrete, producing high quality concrete, both in the fresh and hardened state.

#### 4.2 Review report on dry and wet classification of filler materials for concrete.



Due to high and often variable content of fines (i.e. material less than 125  $\mu\text{m}$ ), in crushed sand, it is a necessity to be able to reduce and enable control of the amount of fines. This could be done either by wet- or dry processing of the sand.

This report<sup>6</sup> reviews some of the most common processes for both wet- and dry classification applied for manufactured sand. Some cases of experience in use are reported. Eventually in the report, a set of factors are discussed when selecting the most appropriate system and equipment for classifying manufactured sand. It is the anticipation that this report will assist aggregate producers in selecting appropriate equipment in order to produce high quality manufactured sand at a reasonable cost.

### Recommendations

A set of factors will be decisive when selecting the most appropriate system and equipment for classifying aggregates, especially manufactured (crushed) aggregate. Some of these are:

- Requirements for the end product – accuracy, customer expectations. Interaction between user requirements for final material and the need for/ requirement to aggregate processing
- The total quarry layout – interaction between crushing, sorting, logistics
- Dependency on local setting (availability of water and locations for sludge deposits)
- Climate conditions, recipients
- Price/running cost
- Volume and product requirements will decide the ambitions for plants; when are the advanced plants needed and when can we do with more simple solutions?
- Local quarry concept – the total cost (economy and environment) comparing local investments/conflicts with the costs of long transport.

The table on the next page intends to summarize some of these issues, relating levels of wet and dry processing respectively to the relevant situation regarding crushing process, environmental issues and market situation.

|                                       | <i>Wet processing</i>  |  | <i>Dry processing</i>  |   |
|---------------------------------------|--|--|--|---|
|                                       | Simple washing   | Hydro cyclones for classifying   | Simple air screening   | Advanced air classifying  |
| <b>Crushing status</b>                |  |  |  |   |
| Simple crushing, few steps            | Wet processing in this case is seldom appropriate, unless some size fractions are heavily contaminated   |  | In case normal dry sieving is not sufficient for fines removal, simple air screening should be appropriate         | The user needs and market for these materials will seldom justify big investments in classifying                                    |
| Advanced crushing, with cubicising    | A too simple solution, after heavy crushing investment, more advanced classifying will normally be relevant  | Can be a relevant solution depending on environmental conditions   | Can be used to simply reduce fines content, depending on which qualities are requested in the market               | Probably the main case where such investments are justified, but depending on moisture content                                      |
| Combination sand / crushed aggregates | Due to moisture in the sand, classifying would need to be the wet way. But normally in these cases grading is being designed/adjusted just by blending the crushed and natural sand curves   |  | Could be relevant for reducing fines content before blending   | Hardly the case for an advanced air classifying, neither from economic nor technical point of view                                  |
| Surface contamination after crushing  | Could be a cheap and useful treatment in this case   | Can be relevant if combined with grading adjustment  | Not relevant in this case  |   |
| <b>Environmental issues</b>           |  |  |  |   |
| Availability of water and recipient   | Availability of water supply and a recipient / opportunity for mud/sedimentation pond will be a must   |  | The absence of water supply and of opportunity for sedimentation is a key argument for choosing dry processes      |   |
| Winter conditions                     | In general, wet processing should be avoided during winter conditions. Also out-door storage of wet-processed aggregates can give frozen stocks for a long time after winter   |  | Winter conditions normally is one of the best arguments for using dry processing                                   |   |
| Logistics, distance to market         | Two basically contradictory considerations, depending on specific case; 1) High cost/high value materials will be justified with long transport distance to high quality markets, since the relative weight of production cost decreases with long transport distances, 2) Use of advanced processing can be justified if it enables the use of local raw materials instead of long transport of remote resources. |  |  |   |
| <b>Market situation</b>               |  |  |  |   |
| Production / sales volume             | Relevant for small to medium volumes   | Big investments will need a high sales volume  | Mostly for medium volumes and stable production  | Big investments will need a high sales volume   |
| User requirements, quality ambitions  | Mostly relevant for more local markets without big focus on quality properties.  | Quality requirements, a need to keep stable products with respect to grading and cleanness   | Quality requirements, but without a need to be able to vary the composition depending on customer requests         | Quality requirements and a need to be able to adjust properties to meet different customers' requests will justify expensive plants |
| Mostly concrete market                | Suitability depending on the composition of origin materials and specific requirements, but moisture content will need to be controlled  | System has proved effective in achieving and keeping a wanted grading. But water content in the product must be kept under control | Will probably not contribute to a designed grading for crushed sand, mostly to remove fines from the coarser sizes | Probably the technologically best alternative for both these types of aggregate   |
| Mostly asphalt market                 |  | Too advanced and expensive to be justified only for such purpose   | Could be a good alternative if the crushed materials have high fines content                                       |   |
| Road base and general market          |  |  |  |   |



## 5 Various COIN Reports and Papers

### 5.1 Classification and Particle Properties of Fine Aggregates (< 63µm) – Applied as concrete aggregate.



The main task of this report by Wigum (2011)<sup>7</sup> was limited to carry out both simple and more advanced particle characterisation of fine aggregates (< 63 µm), intended for the use as concrete aggregates. Simple tests were defined as tests that can be done on the fines with relatively simple equipment. Characterization tests were classified as tests done on the fines that need to be done in specialized facilities or with highly specialized equipment. They are useful in research for determining exact characteristics of the fine aggregates, but are not able to be done in the field, in a quarry lab, or similar setting. It is assumed that the different test methods do not necessarily characterise the properties of the fines in the same way. It is the ultimate aim to find which tests, simple or more advanced, that mirror in a best way the effects of the properties of fines as

concrete aggregate. This includes both the fresh and hardening state of concrete, and strength and durability issues during the service life of the concrete. Within the frame of this project it was not carried out experimental work with concrete or mortars, but this project will add an important basis for a possible follow-up project to look into these issues.

The various materials tested are both of natural and/or crushed aggregates origin. Methods of characterisation were selected based on available methods at the Particle Characterisation Laboratory at the Department of Geology and Mineral Resources Engineering, NTNU. The Particle Laboratory is specialized in this type of characterization, i.e. analysis of particles using a variety of different measurement principles and equipment. The most common assays are the measurement of particle size, surface, grain shape, weight and porosity.

#### Conclusions – Final remarks

The ranking of the results of the NZ Flow Cone Test is a qualitative subjective assessment in this project based upon the judgment provided by the method. For the particle size distribution, it is evident that the measurement by the SediGraph is exhibiting a coarser grading than measured by the Coulter. Looking at the approximate amount of material passing the 10 µm size, the SediGraph exhibits results with a factor of 1.2 to 1.5 larger when

compared to the results by Coulter. The Pharmavision 830 Image analysis results are presented as average results for all particle sizes tested, i.e. 0-63 $\mu$ m. As a consequence it is not possible to make any conclusions if particular particle grain sizes are exhibiting particular properties that may affect the utilisation in concrete. Data from the image analyser device; AnaTec, carried out by Norsk Stein (Odd Hotvedt, pers. med. 2010) showed that the grain shape (length/width) was significantly worse (for several samples) for particle sizes of 200  $\mu$ m and 30  $\mu$ m, compared to other particle sizes. This needs to be investigated further. As no mortar- or concrete tests have been carried out within this project with these particular filler materials, it is difficult to assess how these materials, and which particular properties that may affect the mortar and concrete qualities. Further research is needed on the characterization of selected properties of fillers, and subsequent mortar- and concrete testing with the same filler materials.

## 5.2 Hokksund Quarry – Review of the aggregate production



Hokksund Quarry was visited and reviewed in order to make assessment of the potential of using the current 0/4 mm aggregate in concrete from the quarry as it is today, i.e. already crushed and stored with today processes.

In this report by Wigum (2011)<sup>8</sup> the production process is described, along with consideration regarding challenges regarding storage and segregation of 0/4 mm materials. Some preliminary results on concrete mix design are presented, along with some future scenarios for optimized production of manufactured sand (0/4 mm).

Aggregate materials from Hokksund quarry have been delivered to Tampere, Finland for test VSI crushing at the test plant of Metso. Subsequent concrete mix design and testing of those materials was carried

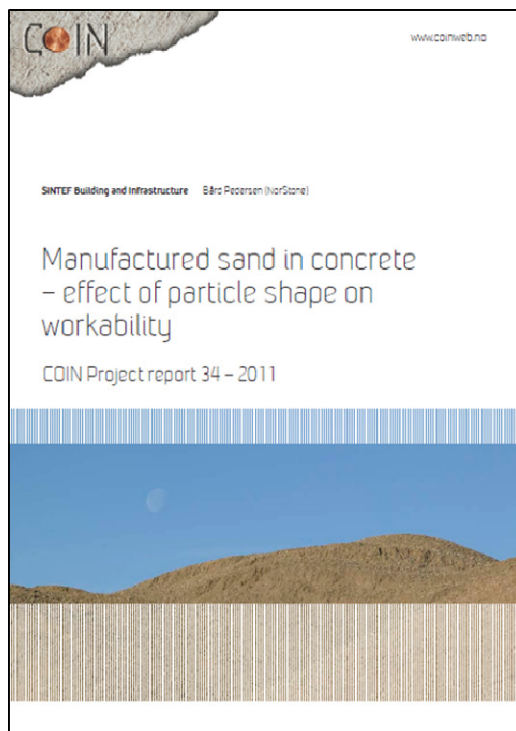
out as part of another study (Cepuritis, 2011).

### Future scenario for optimized production of manufactured sand (0/4mm)

In order to optimise the future production of 0/4 mm manufactured sand, several scenarios were discussed:

1. Installation of VSI crusher and air classifier.
  - 1.1 Adjustments and configuration of the cone crushers – evaluate the potential of the cone crushers.
  - 1.2 Optimise the storage conditions – dry storage with procedures regarding storage and handling to avoid segregation.
2. Start trials with the materials at Loe Concrete producer.

### 5.3 Manufactured sand in concrete – effect of particle shape on workability



#### Summary

The main objective of this study by Pedersen (2011)<sup>9</sup> was to investigate how the particle shape of the fine aggregate affects the rheological properties of concrete. The work was carried out on mortar; or technically more correct on “mini concrete” with 8 mm maximum aggregate size.

Materials with a range from very poor to very good with respect to particle shape were chosen for the study. Each material was sieved into fractions 0.125/2 mm, 2/5 mm and 5/8 mm. Standardized filler was used to eliminate the filler effect. Three different qualities of crushed materials were sampled from the Tau production plant, among these two intermediate qualities with relatively poor particle shape. In addition, crushed materials from the quarries of Jelsa and Hokksund were included in the study. Årdal NSBR natural

aggregate from the Årdal quarry was reference in this study.

The fresh properties were quantified by the use of slump and slump flow on a flow table also allowing the use of “dumps” to simulate the effect of vibration. The shape of the 2/5 and 5/8 mm fractions were quantified by use of standardized flakiness index (FI). The 0/2 fractions were characterised by use of the NZ flow cone.

In this study, mini-concrete with w/c ratio of 0.44 and 511 kg cement per m<sup>3</sup> were used. In leaner mixes with larger aggregate size and higher w/c ratios the effects may be somewhat

different. However, based on the given mix design in this study we may draw the following conclusions:

- For the fractions 2/5 mm and 5/8 mm the particle shape seems to have relatively little influence on the workability. Aggregate with flakiness index around 15-20 are performing nearly as well as particles from natural aggregate. Even particles with really poor shape (FI up to 50) seem to give relatively small negative influence on the workability. One reason for the relatively small effect of particle shape for these fractions is the relatively low amount of these fractions (20 volume %).
- The 0.125/2 mm fraction seems to have a much higher impact on the workability than the larger sized fractions. The span in slump achieved only by exchanging these fractions was 170 mm, which represents approximately 15-20 % in water and cement demand.
- The effect of VSI crushing for the Tau material is very large. While the Tau-material after 3 steps of gyratory crushing has a rather poor performance, a final step of VSI crushing gives significantly better performance. Hence, there may be a very large potential for shaping the particles < 2 mm size by the use of a VSI crusher.
- The NZ flow cone gives useful information on the performance of the 0/2 fraction. To some extent the performance in fresh concrete seems to be correlated to the flow cone results. However, there is a need for further work on the flow cone to learn how to evaluate these results.

The study presented here has illustrated that the main focus should be on the 0/2 fraction due to its large relative effect on the fresh properties. It seems obvious that VSI crushing is a very useful tool to improve the particle shape for the 0/2 fraction. However, there is a potential to optimize the use of VSI in order to get the best possible effect on the 0/2 fraction. Full scale testing using different VSI setups should preferably be done. There is an obvious need for a reliable characterisation method for 0/2 materials. The NZ flow cone is an interesting approach. It should be further investigated in relation to the performances of a variety of natural and crushed Norwegian materials.

## Conclusions

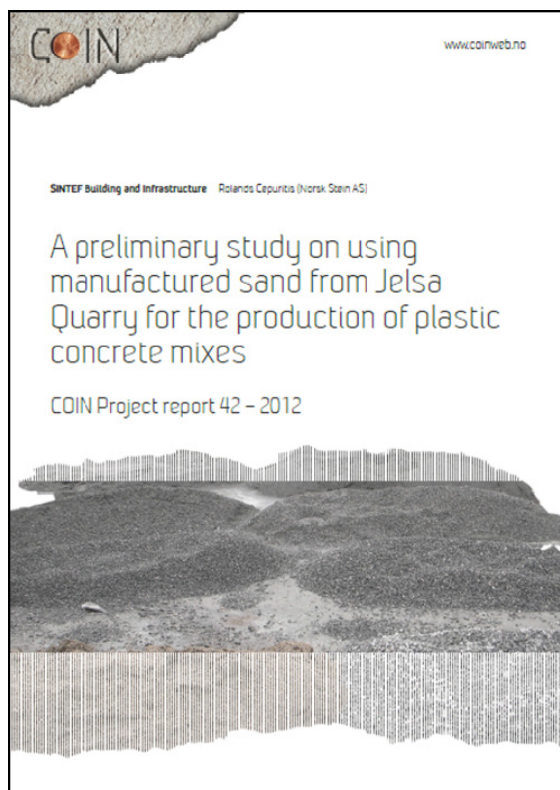
Having the limitations in mind, we can draw some conclusions.

- For the fractions 2/5 mm and 5/8 mm the particle shape seems to have relatively little influence on the workability compared to the 0/2 mm fraction. Aggregate with flakiness index around 15-20 are performing nearly as well as particles from natural aggregate. Even particles with really poor shape (FI up to 50) seem to give relatively small negative influence on the workability. One reason for the relatively small effect of these fractions is the relatively low amount (20 %) of each of these fractions.
- The 0.125/2 mm fraction seems to have a much higher impact on the workability than the larger sized fractions. The span in slump achieved only by exchanging these

fractions was 170 mm, which represents approximately 15-20 % variation in water and cement demand.

- The effect of VSI crushing for the Tau material is very large. While the Tau-material after 3 steps of gyratory crushing has a rather poor performance, a final step of VSI crushing gives significantly better performance. Hence, there is a very large potential of shaping the particles < 2 mm size by the use of a VSI crusher. It should be noted that the VSI process being used at the Tau plant is not optimized for shaping the minus 2 mm particles, but rather to increase the shape of the 5/8 mm and 8/11 mm fractions.
- When the full curve of each material, including filler, is tested it is obvious that materials from Tau, Jelsa and Hokksund have a potential for use in concrete as they are. In particular, this seems to be the case for the Jelsa material which performs excellent even compared to the Årdal reference. The Hokksund material has the poorest performance among the tested materials, most likely due to the very simple process without VSI and without any filler reduction.
- The NZ flow cone gives useful information about the performance of the 0/2 mm fraction. To some extent the performance in fresh concrete seems to be correlated to the flow cone results. However, there is a need for further work on the flow cone to learn how to evaluate these results.

#### 5.4 A preliminary study on using manufactured sand from Jelsa Quarry for the production of plastic concrete mixes.



From 2008 to 03/2010 (start of the study) the concrete produced in a mobile plant in Jelsa quarry for an upgrade/expansion construction project demands was made using natural 0/8 mm sand from and outsource combined with a local granodiorite crushed material ( $D_{max}$  of 16 mm) (Cepuritis, 2013)<sup>10</sup>. Back in 1993 for another construction project within Norsk Stein a usable concrete had been produced using only crushed material from the same rock type and production lines. In October 2009 a preliminary testing of 100% crushed mix design had been carried out in the full-scale production of the new mobile concrete plant but it had been a failure – total separation of the mix. Therefore the main aim of this study was to find a way (an approach to the mix design) how to produce concrete on 100% local crushed material satisfying the same

demands (pumpability and workability) as the concrete being used for the construction project so far. To gain an economical benefit from the study new mixes should have been with a lower concrete self-price as the ones made with the natural sand. In total 42 laboratory tests were completed to find a mix composition (grading and matrix volume l/m<sup>3</sup>) providing the lowest water demand while still producing a normal vibrated structural concrete according to the demand from the project. This report contains information about the reference concrete from 0/8 mm natural sand, used approach for the laboratory tests and a summary of all the test results.



## Conclusions

The preliminary tests performed show that if the manufactured sand from Jelsa quarry (with a sharp particle shape) is used for a dense grading, the result gives a harsh mix, requiring much of fines (matrix volume) to compensate the voids content - increasing the water demand. Experience of traditional natural sand concrete mix design should not be automatically transferred for use with Jelsa material as the results most likely will show an undesirable result. A completely new approach should be developed. The best aggregate composition for Jelsa crushed material from the point of water demand and flow properties of the mix is the gap-grading from 2-8 mm. Though, it should be also stated that gap-grading is not the key to obtain good results. For example, a straight-graded mix would give the same results but with an increased water demand (a need for higher matrix volume to achieve the same fresh concrete properties). The gap-grading is also less suitable for the production of self-compacting concrete (SCC). Using gap-grading from 2-8 mm could also be beneficial from the point of aggregate sales because 5/8 mm material has a good market for other products than concrete.

The gap-graded mix design includes a lot of 0/2 mm unwashed material that is very rich in fines (~26% passing the 0.125 mm sieve). When left outside in rain the material could acquire a moisture content of up to 13%. When the moisture was higher than 9 % laboratory tests indicated repeatability problems. This could also be an issue in real concrete production as well as moist material blockage in the aggregate silos and dust problem in the storage if the 0/2 mm material is very dry in the summer time. It was hard to compare fresh properties of natural and manufactured sand concrete using only simple tests methods available for this study. The “look” of manufactured sand concrete until a certain matrix volume is completely different and since there was no prior experience with this material it was hard to draw up a border at which matrix volumes the concrete is still pumpable. The results (minimal matrix volume of 395 l/m<sup>3</sup> for w/c=0.57, STD cement and gap-grading 2-8 mm) from the laboratory tests must be therefore verified by full-scale pumping experiments in the quarry building site. Manufactured sand from different sources (Tau and Jelsa) can give different results in concrete (water demand) when the same grading is used. This means that the shape of the particles in some fractions is very important and crusher type, settings and the number of crushing steps will determine the suitability of manufactured sand for the concrete production. It is not totally clear which fractions are the most important. The previous results from the manufactured sand tests in mortars ( $D_{max}$  of 8 mm) could not be applied straight-forward to concrete with a  $D_{max}$  of 16 mm.

## 5.5 Resource Management and a Best Available Concept for Aggregate Sustainability

### Abstract

In an article by Danielsen & Kuznetsova, (2014)<sup>11</sup> it is presented that aggregates are major constituents in construction, the global request for which approaches some 22 billion tonnes per year. Some major challenges follow; first of all the dependency on geological conditions and the availability of resources; secondly the traffic, emissions and energy use connected with transportation; thirdly the technology of utilising resources with a variety of properties to meet user requirements; and finally – getting more awareness – the land use conflicts and

environmental impact of the aggregate and quarrying industry, and the need for making these activities sustainable.

Aggregate standards have primarily been written by engineers. And engineers are first of all concerned with technical requirements. However, in the future, there will be a greater focus on environmental impact and sustainability.

Geological resources are non-renewable, which e.g. can be seen in the rapid depletion of natural sand/gravel deposits. This causes increasing awareness along with environmental impact; conflicts of interest concerning land-use; sustainability in mass balance; and not least – increasing transport distances required to get the materials to the places of use.

The principle of a Best Available Concept (BAC) for aggregate production and use is introduced, working with four essential phases: Inventory and planning, Quarrying and production, Use of aggregates, and Reclamation of mined-out areas. In order to compare alternatives and calculate environmental and economic consequences of decisions, it is recommended to work with new LCC (Life Cycle Cost) and LCA (Life Cycle Assessment) tools recently developed in two EU (European Union) funded research projects.

## **5.6 Environmental Impact and Sustainability in Aggregate Production and Use**

### **Abstract**

In an article by Danielsen & Kuznetsova, (2014)<sup>12</sup> it is presented that for aggregates as for most engineering materials and processes, standards have been written by engineers. And engineers are first of all concerned with technical requirements – megapascals, E-modules, abrasion values etc. However, in the future, probably the environmentalists will take over much of the standardisation work. And they will focus on environmental impact and sustainability.

Already we see a fast increasing awareness from society when it comes to the exploration, quarrying, production and use of mineral resources: The non-renewable character of the resources; the environmental impact on neighbourhood and nature; the conflicts of interest versus preservation, groundwater, agriculture and building areas; sustainability concerning mass balance and deposition of surplus sizes; and not least – the ever increasing transport lengths required to get the materials to the places of use.

Actions should be taken to meet these challenges by following up the principles of a Best Available Concept (BAC), as suggested in the EU project EcoServe. This concept works with four essential phases: 1) Inventory and planning, 2) Quarrying and production, 3) Use of aggregates in construction, and finally 4) Reclamation of mined-out areas. In order to compare alternatives and calculate/foresee the environmental as well as economic consequences of choices and decisions, it is recommended to work with new LCC and LCA tools recently developed in two EU funded research projects.

### **5.7 An All-Integrated Concept for Resource Efficient Production and Use of Aggregates.**

#### **Abstract**

It has been presented by Danielsen & Velde, (2014)<sup>13</sup> that a fast coming shortage of traditional aggregate resources, firstly sand and gravel, has led to a need for alternative sources and technologies. Norway has seen a development towards more crushed aggregates from hard rock. Sustainability concerning access to and handling of aggregate resources is a challenging issue for an industry supplying highly needed materials, an industry which also is responsible for building up huge stockpiles of un-sellable crusher fines. Important elements of sustainability are resource efficiency, no-waste production, recycling and effective logistics. The Velde plant to be presented provides a state-of-the-art concept for handling these four sustainability elements inside one plant. The core of the plant is an advanced system for producing purpose designed high quality fine aggregates from crushed rock, which is co-located with asphalt and concrete factories, as well as a recycling facility. This enables a complete integrated system with minimum transport logistics needed, and no waste generated.

### **5.8 COIN Project: Towards a Zero-Waste Technology for Concrete Aggregate Production in Norway"**

#### **Abstract**

As presented by Cepuritis & Danielsen, (2014)<sup>14</sup> the aggregate production is a mining operation where no purification of the "ore" is necessary. Still it is extremely rare that an aggregate production plant is operating on the basis of zero-waste concept. This is since historically the fine crushed aggregate (particles with a size of less than 2, 4 or sometimes 8 mm) has been regarded as a by-product or waste of the more valuable coarse aggregate production. The reason is that the crushed coarse aggregates can easily replace coarse rounded natural stones in almost any concrete composition; while, the situation with the sand is different. The production of coarse aggregate normally yields fine fractions with rough surface texture, flaky or elongated particles an inadequate gradation. When such a material replaces smooth and rounded natural sand grains in a concrete mix, the result is usually poor and much more water and cement has to be used to achieve adequate concrete flow.

The consequences are huge stockpiles of the crushed fine fractions that can't be sold (mass balance problems) for the aggregate producers, sustainability problems for the whole industry and environmental issues for society due to dumping and storing of the fine co-generated material. There have been attempts of utilising the material in concrete before; however, they have mostly ended up in failure. There have been attempts to adjust the crushed sand to the properties of the natural sand, which would still give a lot of waste, especially if the grading would have to be adjusted and the high amounts of fines abundantly present in the crushed sand would have to be removed. Another fundamental reason for failure has been that historically such attempts have mainly ended up in a research carried out by people (both industrial and academic) with aggregate background (= parties willing to

find market for their crusher fines) providing only conclusions already well known by the engineers involved in concrete production.

Due to the pressing situation with the left resources of the natural sand and gravel in Scandinavia, a new and different development approach has been recently attempted with the Concrete Innovation Center (COIN) in Norway. The centre is a research based innovation project that has brought together and served as a source of funding to facilitate the crucial interaction between the professionals from the different involved industries (quarrying machinery supplier, aggregate producers, concrete producers and concrete contractors) and the academic people from universities and research institutions, in order come up with a better crushed sand solution for the future. The concept under development has been a zero-waste technology for aggregate production, where instead of reducing the amount of the crushed fines their properties are rather engineered to crucially increase the overall performance of the sand in concrete. The project also involves collaboration with a state-of-the-art aggregate production plant where the new technology has already been implemented. The production process there is based on the new engineered sand concepts successfully supplying 100% all of the produced fractions to concrete and asphalt producers.

### **5.9 More sustainable resources. (In Norwegian; Mer bærekraftige byggeråstoffer") – Presentation at the NGU-day 2014, Trondheim.**

#### **Abstract**

"More sustainable raw materials for construction" was the theme for a lecture at the annual NGU conference in January 2014 (Danielsen, 2014)<sup>15</sup>. Estimating that some 80 % of all sand/gravel ever being extracted from nature has been extracted during our generation, it is claimed that the access to materials resources will be one of the major global market-drivers in the years to come. This will be followed by an increased focus from society when it comes to environmental impacts and sustainability. Geological resources are by nature non-renewable, which will call for careful and holistic planning to meet materials requirements along with all the other needs in the society relating to use of land, emissions, waste deposits, environmental impacts to neighbourhood, transport of materials. Mineral resources can only be extracted where nature has placed them, but they must be used where society needs them. And that is not necessarily the same place. So it has to be discussed if aggregate supply should be based on local production, or the materials should be transported over big distances. Which criteria should apply, what priority will be given to environmental issues, and how will public authorities consider the need for local availability of materials versus all other needs in their land-use planning.

**5.10 Environmental impact, the future criteria of selecting aggregates (In Norwegian; Miljøbelastning, fremtidens kriterium for tilslagsvalg") – Presentation at the conference; Stein i Vei 2013, Stavanger.**

**Abstract**

"Environmental impact – the future criteria for aggregate selection" was presented as a lecture at the annual "Stone in roads" conference in February 2013 (Danielsen, 2014)<sup>16</sup>. Being traditionally written by engineers, it is a fact that materials standards are mostly focused on physical and mechanical properties. In the future, however, the society will to a much larger degree request the environmental profile and impact of the materials. This will include factors like CO<sub>2</sub> emission and energy use connected with production and transport, harmful emissions, mass balance to avoid the building up of large waste deposits, disturbances to the neighbourhood from dust, noise and transport, the sustainable use of resource, land use and land reclamation. LCA/LCC methodologies and software is available, which could be used to establish a new and alternative way of performing a holistic decision support, incorporating all these (and more) factors. This could also be a valuable tool in the technical/economic implementation of crushed sand technology.

**5.11 Filler from crushed aggregate for concrete: Pore structure, specific surface, particle shape and size distribution.**

**Abstract**

In this paper (Cepuritis et al., 2014)<sup>17</sup> characteristics of fine particles (0 µm to 125 µm diameter) from seven different crushed and natural sands from five different Norwegian rock types were determined. The results suggest that the same water absorption values, as determined by EN 1097-6 on coarser sand fractions, can be applied to the fines. The values of specific surface area measurements vary widely between different materials and measurement methods. BET measurements seem to be strongly affected by the mineralogical composition (presence of mica) and surface morphology (weathering) of the particles. Specific surface area calculated from the particle size distributions (PSD) is mainly dependent on the precision of the test methods in the size range below about 3 µm to 5 µm, since these small particles contain most of the surface area. Shape measurements by both dynamic image analysis (DIA), which is a 2-D method, and X-ray microcomputed tomography (µCT), which is a 3-D method, have been demonstrated to be able to yield similar relative length-to-thickness aspect ratios of the particles between different mineralogies, though with lower absolute values for DIA due to 2-D projection of 3-D quantities.

### **5.12 Research project on manufactured sand for concrete.**

#### **Abstract**

This paper (Cepuritis et al., 2014)<sup>18</sup> very briefly reports on progress made in an industrial PhD-project on crushed sand production for concrete investigating how to control the variability with respect to fresh concrete properties. This includes production of model materials from a wide range of relevant Norwegian bedrocks using a new technology (VSI and air-classification), particle characterisation and studies of fresh concrete rheology. The model material production is described and some preliminary results on characterisation are presented. The further work will include development of micro-proportioning technology to exploit the best properties of fillers and adapt these to different types of cement and other binders.

### **5.13 From manufactured to engineered sand for concrete.**

#### **Abstract**

In a paper (Cepuritis et al., 2014)<sup>19</sup> it is proposed new technology includes combining an existing static air-classification technique for crushed sand with a concrete proportioning model that allows an industrial scale optimization and development with respect to the choice of aggregate fillers, binders and admixtures for controlling workability and rheology of concrete. Going “from MANUFACTURED to ENGINEERED” sand basically includes taking the current state-of-the-art crushed fine aggregate production process (i.e. the MANUFACTURED sand approach) to a whole new level. This is a game changing innovation in the otherwise rather inert and conservative aggregate production technology field and at the same time enables considerably improving the sustainability of this industry. While the conventional MANUFACTURED sand concept generally includes only reducing the amount of fine particles generated during the crushing and shaping processes (such as the last step impact crushing), the ENGINEERED sand approach aims at also optimizing the grading of the sand with/ and filler part itself. This is achieved with sand air-classification equipment that is readily available for full scale production today. To allow ENGINEERED sand to be competitive on the market, a development of micro-proportioning technology that can exploit the best properties of fillers that are present in high amounts in crushed fine aggregates and adapt these to different types of cement and other binders is under development. This includes detailed study on effect of the process of producing crushed fine aggregate for conventional and self-compacting concrete (SCC) while maintaining control of the rheological properties of fresh concrete. Briefly this is done by quantifying particle and surface characteristics of a wide range of bedrock sources for crushed fine aggregate production and their behaviour in fresh cement based materials. The paper then briefly summarises the described crushed sand development work completed and still under progress within the COIN project.



#### **5.14 Fra maskinsand til høykvalitets tilslag for betong (engineered sand). (partly in Norwegian).**

##### **Sammendrag**

I denne artikkelen (Cepuritis, 2013)<sup>20</sup> presenteres det at den globale etterspørselen etter tilslag er i dag økende. Som et resultat blir eksisterende egnede sandressurser tømt med omtrent samme hastighet som urbaniseringen. Dette har ført til en situasjon der de naturlige sandressursene, som tidligere ble tatt for gitt, nå er brukt opp rundt mange tett befolkede områder i Norge og Sverige. Produksjonen av grovt tilslag gir normalt fine fraksjoner med ru overflatetekstur, langstrakte eller avlange partikler, og utilstrekkelig gradering. Hvis et slikt materiale erstatter de glatte og avrundede naturlige sandkornene i en betongblanding, blir resultatet vanligvis dårlig og mye mer vann og sement må benyttes for å oppnå tilstrekkelig flyt i betongen. På grunn av dette har det lenge vært en generell oppfatning i den norske betongindustrien at det ikke er gunstig å bruke det finkornige knuste tilslaget i betongproduksjon. Imidlertid, med rimelige justeringer i tilslagsproduksjonsprosessen og betongproporsjonerings-prinsipper, kan knust fint tilslag gå over fra å være et biprodukt fra produksjonen av grovt tilslag til å bli høykvalitets knust sand. Det siste spørsmålet at man må da løse er spørsmålet om det høye innholdet av finstoff i knust sand. Artikkelen viser hvordan blir denne saken løst i doktoravhandlingen av forfatteren i et nært samarbeid med COIN-prosjektet. Resultater skal la os flytte fra maskinsand, som er tilslagsproduksjonsstandarden i dag, til høyere kvalitet fint tilslag for betong, dvs. et konsept som blir introdusert som ENGINEERED SAND.

#### **5.15 Manufactured sand crushing process parameters: short review and evaluation for sand performance in fresh concrete.**

##### **Abstract**

Effect of manufactured sand crushing process parameters on performance of crushed fine aggregates in fresh concrete has been evaluated in this paper (Cepuritis, 2013)<sup>21</sup>. Results indicate that the two most important parameters are the number of crushing stages used, reflecting the reduction ratio of the cone crushers, and the crusher type (cone or VSI) used for the last stage. VSI tip speed itself seems to be of a second order of importance; however, changes in fresh concrete rheology were observed when materials processed at high (45 m/s) and low (60 m/s) tip speeds were tested in concrete.

#### **5.16 Visualizing and simulating flow conditions in concrete form filling using pigments.**

##### **Abstract**

In this paper (Jacobsen et al., 2013)<sup>22</sup>, plow variation at surfaces and reinforcement during form filling was visualized with grey and black SCC. The border between grey and black (pigmented) SCC was captured as frozen images on hardened sawn-and formwork surfaces

in a flow box experiment. Maximum velocity occurred at the centre of the closed box, and lowest velocity near the formwork, particularly with reinforcement parallel to formwork. Smooth formwork gave shorter flow profiles (higher surface velocity) than rough formwork. The pigmented mixes had similar workability though somewhat increased yield stress. Flow pattern depended on mix rheology, surface roughness and reinforcement: one mix showed plug flow between reinforcement and smooth vertical formwork whereas most mixes mainly had sheared flow. Numerical simulations mostly agreed with observed flow profiles and could be used to model flow at varying formwork surface roughness with a slip velocity. Future investigations should study the conditions causing plug and wavetype flow, lubrication and surface finish.

### **5.17 SCC matrix rheology with crushed aggregate fillers: effect of physical and mineralogical properties, replacement, co-polymer type and w/b ratio.**

#### **Abstract**

In this paper (Cepuritis et. al, 2013)<sup>23</sup> the effect of different mineral fines (0-125  $\mu\text{m}$ ) from crushed and natural Norwegian sands on the rheological properties (Bingham's yield stress  $\tau_0$  and plastic viscosity  $\mu$ ) of filler modified cement pastes have been investigated at different cement replacement levels, w/b ratios and co-polymer types in a parallel plate rheometer. The parameter studies performed show considerable variations due to effects of the different fillers. The particle size distribution of the fillers (or the specific surface) has been shown to be highly important. Finer fillers tend to induce higher plastic viscosity and yield stress than the coarser fillers. However, surface effects related to different mineralogy and particle shape also seem to be important. The effect of which properties will prevail, seems to be dependent on the replacement level (when filler replaces cement), the superplasticiser type as well as the w/b ratio.

### **5.18 Crushed aggregate fines for SCC: specific surface & pore size study.**

#### **Abstract**

In this paper (Cepuritis et al., 2013)<sup>24</sup> it is presented that aggregate (especially the finest fraction) properties have a large effect on the fresh state properties of SCC. Manufactured (crushed) sand with its naturally high filler content can be perfectly suited for SCC production. However, the current understanding on how crushed fines affect properties of fresh SCC is limited. To proceed in the understanding of how crushed aggregate fines affect the properties of fresh concrete, characteristics of fines (0-125  $\mu\text{m}$  (0-0.0049 in)) from manufactured and natural sand of 5 different Norwegian rock types, were determined. These included density by water- and helium pycnometry, water absorption, PSD by laser diffraction and sedimentation as well as specific surface by Blaine and  $\text{N}_2$ -BET. The results show that the absorption can take place as high inner surface adsorption due to very fine pores of a few nm width (possibly mica). Difficulties in interpretation of water absorption measurements due to uncertainty about water density in adsorbed state are discussed. We also propose to distinguish between the very high internal BET surface and the much lower external surface of the particles represented by sedimentation- and laser methods. In

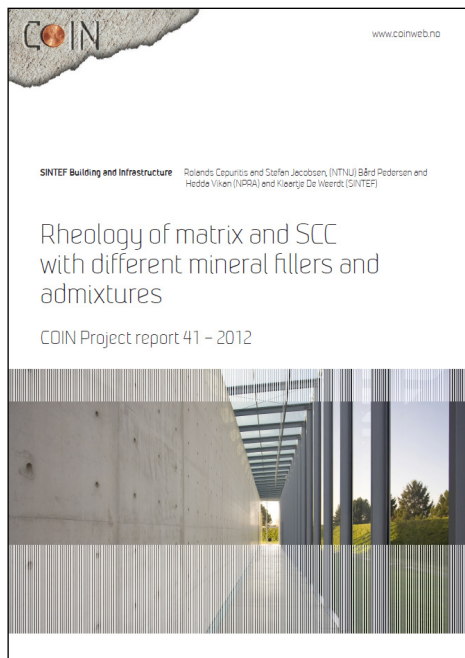
addition, it is proposed that flaky particle shape can increase apparent external surface measured by sedigraph due to increased sinking time compared to less flaky material.

### 5.19 Physical properties of Norwegian mineral fillers investigated by different methods.

#### Abstract

The principal objective and scope of this project work (Cepuritis, 2012)<sup>25</sup> is to obtain a clearer knowledge about the porosity and water absorption properties of the most widely used Norwegian mineral fillers. This would hopefully allow us to discuss the results of specific surface measurements that have been performed with different methods in order to find the “real” surface area of the fine materials.

### 5.20 Rheology of matrix and SCC with different mineral fillers and admixtures.



#### Abstract

The main objective of this study (Cepuritis et al., 2012)<sup>26</sup> has been to obtain a clearer knowledge about the effect of different crushed and natural mineral fillers on rheological parameters of matrix and concrete, in order to answer one of the most important questions when using manufactured sand – the question about the very high filler content.

The effect of 7 widely different fillers on rheology of filler modified paste (= matrix) and SCC was investigated at different w/b ratios (0.4, 0.5, 0.6 and 0.77). The fraction of solids  $\phi$  was kept constant for most of the mixes. A total of 38 matrices were tested which were later “up-scaled” to 22 SCC mixes. Two replacement levels of  $V_{\text{filler}}/V_{\text{powder}} = 0.20$  and  $0.33$  were used in all matrix mixes (equal to the fly ash cement volume fraction in the reference with w/b = 0.4

without filler). Two different types of co-polymeric superplasticizers were used for the studies keeping the dosage constant at the level of 0.4% for the matrix mixes and adjusting the dosage according to the w/b ratio for the SCC mixes.

A Physica MCR300 Rheometer was used for the matrix flow tests (yield stress, plastic viscosity), static tests (yield stress, shear modulus) as well as for oscillatory tests (viscoelastic properties). Fresh concrete properties such as slump-flow, density and air-void content were measured for the SCC mixes along with the rheological measurements being performed on a coaxial cylinder viscometer Viscometer 5 by ConTec.

Within the project filler particle size distribution and specific surface area has been determined using four different characterization methods – sedimentation (Stoke’s law), laser diffraction, Blaine and BET.

The research carried out within this study is a strong foundation in order to fully understand the interaction between different types of mineral fillers and admixtures one hand and rheological properties of cement based particle suspensions such as matrix and concrete on the other. However, based on the results so far it's still more new questions than answers.

First, it is rather clear that most of the available mineral particle characterization methods give very different results and it is still a challenge to get more understanding on this topic. Mineral composition of the fillers has been suggested as one of the possible reasons and further research directions have been proposed. The obtained results confirmed that it is possible to some extent relate the rheological differences of matrices to the specific surfaces of the fillers used to mix them. This seems to also be true for the structural regeneration and decomposition of the filler modified paste. However, the relation was rather limited and other relevant parameters for further studies have been proposed. No relation between the specific surface of the fillers and rheological properties of fresh SCC was found. The flowability of both matrix and concrete mixes was considerably improved when the mineral fillers replaced parts of the finer fly ash cement on volume basis. The natural filler gave the best flowability for both matrix and concrete as expected.

### **5.21 Yield stress and slump-flow of SCC: Short review and application.**

#### **Abstract**

In this paper (Cepuritis, 2012)<sup>27</sup> a short review on the relevant previous work is given and the applicability of an existing analytical model to evaluate yield stress  $\tau_0$  from spread measurements of cementitious suspensions is verified for self-compacting concrete (SCC). Based on limited amount of results included in this work, it is possible to demonstrate the potential of the given model to be used in order to evaluate yield value of a SCC mix from spread measurements performed with a standard slump cone. The model seems to be applicable for mixes with a slump-flow higher than 550 mm, *i.e.* for the complete SCC range.

### **5.22 Innovation in aggregates for concrete; manufactured sand, lightweight aggregate, alkali-silica reaction.**

#### **Abstract**

The wish to avoid waste material from a quarry for manufactured sand production, has created a challenge because of the negative influence of the fines on the workability. The present work (Martius-Hammer, et al, 2011)<sup>28</sup> suggests methods to modify the fines to meet the challenge. Extensive progress has been made in order to develop a consensus method for performance based testing of ASR, allowing utilization of many local potentially alkali-silica reactive aggregates, enhanced flexibility for the concrete producer with respect to material selection and optimization of the concrete mix design. The idea to further develop the expanded clay LWA to get a strong but thin outer shell and a light but strong internal structure has been explored, and the present work show that a considerable strength improvement can be reached without compromising density.

### 5.23 Effect of aggregate crushing on fresh concrete.

#### Abstract

The main results of this work (Cepuritis et al., 2011)<sup>29</sup> indicate that it's possible to measure changes in fresh concrete rheological properties if manufactured fine (0/2 mm) aggregate produced by different crushing processes and containing normalized amount of fines is analysed in concrete. Workability increase due to replacement of a cone crusher with a vertical shaft impactor (VSI) for the last crushing step seems to be of a higher order than changes due to VSI tip speed. Those factors were found to have no effect on rheological properties of the corresponding matrix (filler modified cement paste). It was found that most of the convenient fine aggregate characterization parameters can give an indication of the 0/2 mm crushed sand performance in concrete with respect to rheology. However the order of relation is rather limited and none of them can be used as a fundamental parameter. Loose and compacted packing measurements tend to show a lot better correlation. However the correlation is not perfect and based on the results acquired within the research two other parameters by combining packing and specific surface concepts have been proposed.

### 5.24 Rheology of matrix with different crushed mineral fillers and admixtures.

#### Abstract

In this paper (Cepuritis et al., 2011)<sup>30</sup>, the effect of 7 widely different fillers on rheology of filler modified paste (= matrix) was investigated at  $w/b = 0.50$  and  $0.60$  and  $0.4$  % superplasticizer (SP) of fly ash cement. Two replacement levels  $V_{\text{filler}}/V_{\text{powder}} = 0.20$  and  $0.33$  were used at constant volume fraction of solid particles  $\Phi = 0.459$  in all mixes (equal to the cement volume fraction in the reference with  $w/b = 0.40$  without filler). Two different types of co-polymeric SP were used. A Physica MCR300 Rheometer was used for flow tests (yield stress, plastic viscosity), static tests (yield stress, shear modulus) as well as for oscillatory tests (viscoelastic properties). The main effects observed were highest consistency for natural filler compared to crushed filler, that the magnitude of the effect of SP-type on rheology seemed to be similar or perhaps larger than the magnitude of the effect of filler type. The consistency increased as filler replaced cement at increasing  $w/b$  and constant volume fraction of particles, even as volumetric amount of SP reduced.

### 5.25 SCC flow visualization in formfilling with black and grey concrete.

#### Abstract

In this paper (Jacobsen et al., 2011)<sup>31</sup> studies of flow conditions during SCC formwork filling were made in a new flow box method with black SCC flowing after grey SCC. Flow conditions are visualized after hardening and sawing as a "frozen" image of the border between grey and black concrete. 3 different selfcompacting mixes were investigated with  $D_{\text{max}} 8$  mm and 40 vol-% matrix with  $w/b = 0.50$ ,  $0.65$  and  $0.65$  with Viscosity Modifying Admixture (VMA). The 3 mixes were made in both gray and black with similar rheological properties. The

results show maximum flow rate in the centre of the box near the top and lowest flow rate near the formwork. However, different flow profiles occur, depending on concrete, formwork and flow rate: plug flow between reinforcement and formwork, sheared flow with a wave form, apparently due to flow interaction with regularly spaced vertical reinforcement bars, as well as shear flow seemingly unaffected by the reinforcement bars.

### 5.26 Flyplassdekke med maskinsand. Værnes APRON Vest



This brief report in Norwegian, by Smeplass and Mørtzell (2014)<sup>32</sup> describes a case study of mix-design approach for the new airport concrete pavement at Værnes airport in Trondheim.

The background was that previous concrete pavement (25-40 years old) exhibited cracking due to alkali aggregate reactivity. In the specifications for the new pavement it was strict requirements of using a non-alkali reactive aggregate. As a consequence local natural reactive sand was blended with non-reactive crushed sand from Nord Fosen quarry. The crushed sand (0/8 mm) was of low quality, crushed by cone-crusher as the final crushing stage, hence no optimisation regarding grain shape or content of fines.

The new concrete pavement (28,800 m<sup>2</sup>, 350 mm thick) was placed in the period of April – October 2012. The sand aggregate (0/8 mm) used was a

blend of 500 kg crushed sand and 425 kg natural sand in a m<sup>3</sup> of concrete.

The casting of the concrete was a great success. The concrete pavement showed a very limited numbers of cracks. It is stated that the crushed sand increased the stiffness and tensile strength of the concrete. It appears that this crushed sand from Nord Fosen (or similar quarries in the region) can be beneficial for certain applications.



### 5.27 Mikroproporsjonering med fillere fra Velde: Effekt av sammensetning på matriksens flytmotstand (2015)<sup>33</sup>



Crushing of rock to concrete aggregates has traditionally produced surplus fines, no matter if the production is intended for coarse aggregates, or manufactured sand. If the crushing includes so-called cubization by a Vertical Shaft Impact (VSI)-crusher, the amount of surplus fines usually increases. Cubization is desired because it gives improved particle shape, both for coarse and fine aggregate.

It is difficult to utilize the fines in concrete production because a high content of fines gives increased viscosity and hence reduced castability. This must be compensated with increased cement content, water content and plasticizing additives. These measures give increased costs and technical drawbacks like increased shrinkage and increased curing temperature.

The aggregate-, concrete- and asphalt producer Velde AS in Sandnes has a total of eight aggregate fractions available for concrete production, all crushed from the same rock. The three finest fractions are separated with an air classifier. This gives the possibility to control the aggregate particle size distribution for each concrete mix down to the filler level.

## 6 Trade journals and Newspapers

### 6.1 Sand from the Rocks

Processing

### Sand from the Rocks

New type of crushed sand to replace natural sand in concrete production

The availability of natural sand for concrete production is facing challenges, while the so-called waste stockpiles at aggregate crushing areas are causing problems for producers. This means that the industry has a huge need to solve this challenge by finding suitable technology for usable crushed sand production.

ROLANDS CEPURITIS\*

Issues related to aggregate prices, sales and technical issues of the production are usually among the topics of concern to quarry managers. Another issue is the mass balance of production because, as part of a normal production process of crushed aggregates, up to 30 percent (rock dependent) of the material acquired from the bedrock is reduced to sizes smaller than 4 mm and thus cannot be used as coarse aggregates.

The co-generated material has long been the most unfavorable fraction in terms of assuring a profitable mass balance, since it can be hard to sell or even to get rid of at any price. As a result, in many places there are huge stockpiles of this "waste" that not only affects the profitability of the aggregate operation, but also causes environmental issues.

On the other hand, in the past few decades, the availability of suitable natural sand for concrete production near the point of consumption has been exhausted around many populated regions in the world. This has led to a search for a new replacement material: the aforementioned surplus fines from crushing operations are expected to be the next best alternative – due to both great availability and suitable physical properties.

#### Natural Sand and surplus Quarry Fines – Differences

Early attempts to use this co-generated material as fine aggregate were mainly unsuccessful. However, today the important differences between natural sand and surplus quarry fines are well known by aggregate producers, and there are examples of the producer successfully overcoming the challenge after working in close cooperation with Miesco.

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42 | *bulk solids handling* | No 3 | 2014

The availability of natural sand for concrete production is facing challenges, while the so-called waste stockpiles at aggregate crushing areas are causing problems for producers.

This means that the industry has a huge need to solve this challenge by finding suitable technology for usable crushed sand production (Cepuritis, 2014)<sup>34</sup>.

### FROM STOCKPILE TO SAND

The availability of natural sand for concrete production is on the decline while so-called "waste" stockpile areas are causing problems for quarries. Rolands Cepuritis explains how the industry can solve this twin dilemma.

Issues related to aggregate prices, sales and technical issues of production are usually among the topics of concern to quarry managers. Another issue is the mass balance of production because, as part of a normal production process of crushed aggregates, up to 30 per cent (rock dependent) of the material acquired from the bedrock is reduced to sizes smaller than 4mm and thus cannot be used as coarse aggregates.

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#### SAVED SURPLUS QUARRY FINES

Early attempts to use this co-generated material as fine aggregate were mainly unsuccessful. Today the important differences between natural sand and surplus quarry fines are well known by aggregate producers and there are examples of the producer successfully overcoming the challenge after working in close co-operation with Miesco.

With respect to particle shape, this includes optimizing the crushing process along with rock-on-rock crushing as the end. This can result in a particle shape that closely resembles that of natural sand.

The issue of the high fines content can be resolved with either wet or dry processing, as different wetting techniques or an classification. Finally, if the sand particles are stacked and classified into naturally narrow particle sizes of a good shape, they can be successfully used as high quality manufactured sand.

#### CRUSHED SAND PRODUCTION

Developing new approaches in the field of crushed sand production and their increasing mass share is not a simple task, one of the reasons being that it involves many parameters. This can be illustrated as a sort of "craze", starting with rock blocking in a hard rock quarry, advancing to rock crushing and screening, then controlling a ready mix producer and finally ending up at the construction site, where the crushed sand concrete is to be evaluated by the end user.

In the contractor's view, to bring all the involved parties together to solve the challenge, the European Concrete Innovation Centre (ECIN) was founded in 2006. Since 2009, Miesco has been an active and key participant in a COIN project on high quality manufactured sand for concrete.

This focus area has served as a source of funding and a hub for facilitating the crucial networking between professionals from the different industries involved and universities and research institutions. The purpose has been to assess a better crushed sand solution for the future.

There are two scenarios for a new approach to crushed sand production. One includes choosing the best available geological resources and then trying to copy Mother Nature by putting serious effort into the shaping of the aggregates and the design of grading curves.

Another approach involves finding ways to make crushed sand perform as well or better than natural sand by altering its intrinsic properties. This also includes developing a new concrete mix design philosophy adapted to crushed sands with specially engineered properties that are different from those of natural sands. The latter has been chosen as the philosophy for the new approach of crushed sand production under development within the COIN project.

It is also worth mentioning that crushed fine

22 | *Quarry* | July 2014

### 6.2 From Stockpile to Sand.

The availability of natural sand for concrete production is on the decline while so-called "waste" stockpile areas are causing problems for quarries. Rolands Cepuritis (2014)<sup>35</sup> explains how the industry can solve this twin dilemma.

### 6.3 New type of crushed sand to replace natural sand in concrete production

R&D

Study by Rolands Cepuritis

## New type of crushed sand to replace natural sand in concrete production

The availability of natural sand for concrete production is facing challenges, while the so-called waste stockpiles at aggregate crushing areas are causing problems for producers. This means that the industry has a huge need to solve this challenge by finding suitable technology for usable crushed sand production.

TEXT Rolands Cepuritis. PHOTOS Rolands Cepuritis and Metso

Issues related to aggregates prices, sales and technical issues of the production are usually among the topics of concern to coarse aggregate quarry managers. Another issue is the mass balance of production because, as part of a normal

production process of crushed aggregates, up to 30 percent (rock dependant) of the material acquired from the bedrock is reduced to sizes smaller than 4 mm and thus cannot be used as coarse aggregates.

This co-generated material has long been the most unfavorable fraction in terms of assuring a profitable mass balance, since it can be hard to sell or even to get rid of at any price. As a result, in many places there are huge stockpiles of this "waste" that not only affects the profitability of the aggregate operation, but also causes environmental issues.

**“In many places the availability of suitable natural sand for concrete has been exhausted”**

On the other hand, in the past few decades, the availability of suitable natural sand for concrete production near the point of consumption has been exhausted around many populated regions in the world. This has led to a search for a new replacement material; the aforementioned surplus fines from crushing operations are expected to be the next best alternative—due to both great availability and suitable physical properties.

**Well-known differences between natural sand and surplus quarry fines**

Early attempts to use this co-generated material as fine aggregate were mainly unsuccessful. However, today the important differences between natural sand and surplus quarry fines are well known by aggregate producers, and there are examples of the producer successfully overcoming the challenges after working in close cooperation with Metso.

With respect to particle shape, this includes optimizing the crushing process along with vertical shaft impact (VSI) crusher, rock-on-rock shaping at the end. This can result in a particle shape that closely resembles that of natural sand.

The issue of the high fines content can be resolved with either wet or dry processing, i.e. different washing techniques or air classification. Finally, if the sand particles are sieved and classified into reasonably narrow particle sizes of a good shape, they can be successfully used as high-quality manufactured sand already today.

28 SINTEF MINDS & SKILLS 2014

The availability of natural sand for concrete production is facing challenges, while the so-called waste stockpiles at aggregate crushing areas are causing problems for producers. This means that the industry has a huge need to solve this challenge by finding suitable technology for usable crushed sand production (Cepuritis, 2014)<sup>36</sup>.

Dagens Næringsliv | Fredag 7. november 2014

## Kortreist stein løser knipe

Grusforekomster blir stadig mindre tilgjengelige som materialressurs for byggenæringen. Knust fjell kan bli redningen.



Verdens pukkverk er fulle av lagret finknust masse som ikke lar seg utnytte. Foto: Omsby Rukk/Norcem, iStock

**Teknologi**  
Svein Willy Danielsen  
Børge Johannes Wigum  
Rolands Cepuritis

Med alle vann- og mineralrike råstoffer den naturressursen verden bruker med seg. Tilgang på sand, grus og knust stein er en forutsetning for de fleste byggeprosjekter. Under navnet tilslagsmaterialer, utgjør disse råstoffene hoveddelen av asfalt og betong.

Tilslagsmaterialer kan kun hentes ut der naturen har plassert dem, men må anvendes der de trengs. Norge bruker nå mer energi på å transportere enn å produsere slikt råstoff. Men en ny ferdig løsning og bruk av naturressurser er å bruke knust stein i betong og asfalt. Verdens pukkverk er derfor fulle av lagret finknust masse som ikke lar seg utnytte. Men forskning og teknisk utvikling har gitt nye produksjonsmetoder og maskiner som gjør at sanda ligger av knust fjell kan trenge i for eksempel betong, asfalt og asfalter og asfalt. 30 prosent av materialet fra en knuseprosess er finstoff (sand) med kornstørrelse på opptil fire millimeter. Tradisjonelle produksjonsmetoder gjorde det umulig å gi denne massen en kvalitet som kan aksepteres i betong og asfalt. Verdens pukkverk er derfor fulle av lagret finknust masse som ikke lar seg utnytte. Men forskning og teknisk utvikling har gitt nye produksjonsmetoder og maskiner som gjør at sanda ligger av knust fjell kan trenge i for eksempel betong, asfalt og asfalter og asfalt.

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## 6.4 Kortreist stein løser knipe. Dagens Næringsliv | fredag 7. november 2014

Svein Willy Danielsen, prosjektdirektør, Sintef Byggforsk

Børge Johannes Wigum, professor, II, NTNU/Norcem as

Rolands Cepuritis, PhDstudent, NTNU/Norcem as

Grusforekomster blir stadig mindre tilgjengelige som materialressurs for byggenæringen. Knust fjell kan bli redningen.

Nest etter vann er mineralske råstoffer den naturressursen verden bruker mest av. Tilgang på sand, grus og knust stein er en forutsetning for de fleste byggearbeider. Under navnet tilslagsmaterialer, utgjør disse råstoffene hoveddelen av asfalt og betong.

Tilslagsmaterialer kan kun hentes ut der naturen har plassert dem, men må anvendes der de trengs. Norge bruker nå mer energi på å transportere enn å produsere slikt råstoff. Men om myndighetene og bransjen synliggjorde de totale miljøbelastningene, ville de skape økt rom for det kortreiste alternativet knust fjell. Det ville styrke bærekraften til mange byggeprosjekter. Produksjon av tilslagsmaterialer er en viktig distriktnæring i Norge. Innenlands årsforbruk er 12 tonn per person. Men av to grunner har disse råstoffene blitt mer utilgjengelige:

- Norske sand og grusforekomster er i ferd med å tømmes. Knappheten er mest merkbar nær de store byene. Det har økt transporten langveisfra.
- I tillegg vil mange bevare sandressurser fordi de utgjør grunnvannskilder, naturområder, jordbruksarealer, byggegrunn eller bevaringsverdige geologiske formasjoner.

Men om sand- og grusressursene avtar, har Norge fortsatt mye fast fjell. Fordi denne ressursen finnes nesten over alt, er knust fjell et kortreist råstoff. Knust fjell i form av grove tilslagsmaterialer (pukk) har lenge vært brukt i betong og asfalt, ikke minst i Norge. Dette er velkjent teknologi. Utfordringene har vært knyttet til den finknuste delen av massen.

30 prosent av materialet fra en knuseprosess er finstoff (sand) med kornstørrelse på opptil fire millimeter. Tradisjonelle produksjonsmetoder gjorde det umulig å gi denne massen en kvalitet som kan aksepteres i betong og asfalt. Verdens pukkverk er derfor fulle av lagret finknust masse som ikke lar seg utnytte. Men forskning og teknisk utvikling har gitt

nye produksjonsteknikker og bruksmåter som gjør at «sand» lagd av knust fjell kan inngå i for eksempel betong, når bergarten er egnet.

Slik knust sand – maskinsand – lages alt i noen norske anlegg. Ved COIN, et betongfaglig innovasjonssenter som Sintef leder for Forskningsrådet, har vi utviklet kriterier som gjør det mulig å lage høykvalitets betong med tilslagsmaterialer som kun består av knust fjell. Standarder for tilslagsmaterialer har til nå vært konsentrert om krav til blant annet styrke og slitasje. I fremtiden blir det større fokus på miljøkriterier som energibruk, utslipp, trafikkbelastning ved transport, støy og utnyttelsesgrad for forekomster.

Biltransport av tilslagsmaterialer ga i 2012 et CO<sub>2</sub>-utslipp på 110.000 tonn, i tillegg til 30.000 tonn fra innenlands båttransport. Øker den gjennomsnittlige transporten med kun tre kilometer, vil miljøutslippet øke med ti prosent. Dette bør gjenspeiles i politikernes krav til bygge- og anleggsprosjekter. Det bør lages kriterier og regnemodeller som gjør at tilslagsmaterialer kan velges ut fra prosjektets totale miljøbelastning, økonomi og ressursuttak. E39-utbyggingen kunne bli en bra start. Teknologien som muliggjør 100 prosent tilslagsproduksjon fra knust fjell, åpner for mer bærekraftig bruk av byggeråstoff. Ikke bare grunnet kortreist-aspektet, men også fordi den gir mer fullstendig utnyttelse av de knuste produktene. Men skal nyvinningen gjøre en forskjell, trengs politisk vilje til å ta ut masse nær de store byene. For her er forbruket størst, og muligheten for miljøgevinst dermed mest åpenbar. Men samtidig er det her motstanden mot slik aktivitet er størst. (Danielsen, Wigum and Cepuritis, 2014).<sup>37</sup>

## 6.5 Characterisation of fillers > 0.125 mm used in Case Study Velde.

### Summary

This report by Ng et al. (2015)<sup>38</sup> is a compilation of the characterisation methods and results performed at different institutes and companies to analyse four different fillers employed in a sub-project Case study Velde in COIN FA2.3 High Quality manufactured sand for Concrete.

Here, the application of different methods for characterizing four different fillers which were manually sieved to obtain particle size below 125 µm is highlighted. The parameters measured were: thermo-stability, mineral/phase compositions, specific surface areas, particle size distribution, particle shape profile and flow resistance ratio. The first three parameters were measured by thermogravimetric analysis (TGA), qualitative X-ray diffractometry (XRD) and BET method. For particle size distribution, 4 different conventional methods were employed to determine the best measurement method in determining this factor. The methods include: laser diffractometry by Beckmann Coulter Analysis LS13 120 (dry method) and Mastersizer 2000 (wet method), X-ray sedimentation by SediGraph 5100 and imaging analysis by PartAn analysis for fine powders. For shape profiling, PartAn image analysis was also employed. For the last investigated parameter, FlowCyl test was employed to study the flowability of the matrix containing different fillers.

For all the fillers, it was found that despite having similar mineral composition, the amount of these phases differed from filler to filler, which affected the particle size distribution and thus specific surface areas of the filler samples. In general, asphalt fillers were the most XRD amorphous, attributing to the high amount of fine particles which cannot be detected in the



XRD analysis. This was confirmed by BET measurements and PSD determination, where a very high surface area (~30 % higher than the filler possessing the lowest surface area) and contain up to 30 % particles with sizes lower than 10  $\mu\text{m}$ . Fine filler possessed the second highest surface area and fine particles content, but it contained the highest fraction of mica, which can contribute to the adsorption of water when fillers are added to the matrixes. In the case of medium filler, it contained the lowest amount of mica and thus possessed the lowest surface area and highest particle sizes. Finally, sand filler lies in between that of medium and fine fillers. The shape profiles of all fillers were relatively similar, and thus this factor was dismissed as an influencing factor here in the dispersion of matrixes in the presence of fillers.

The characterization of fillers confirmed results from FlowCyl test, whereby matrixes with fine fillers displayed the highest flow resistance, followed by asphalt fillers, sand and finally medium. The trend can be attributed mainly to the fineness of the particles. In the case of fine fillers, the high content of water retaining mica further reduced the flow of matrix, thus causing matrixes containing fine fillers to display the highest flow resistance ratio.

## 6.6 Characterization of fillers with plasticizers: Zeta Potential measurements

### Summary

The zeta potentials of five different fillers and three commercial plasticizers were explored in this report by Ng (2014)<sup>39</sup>. The main purpose was to determine how these materials interact with each other to aid dispersions, in an effort to explain the macroscopic observations of sedimentations and interactions of fines in crushed aggregates with plasticizers. The investigation of the materials is divided into 2 areas and they will be summarized as below:

#### **Area 1** – Understanding of sedimentation observation through zeta potential studies

Three different sets of systems were explored: - cement alone, filler alone and cement/filler. In the cement system, regardless of plasticizers presence, the zeta potential was positive due to the high content of Al containing clinker phases in cement employed, and the ability to form double layer during surface adsorption by the cement particles. For fillers only system, the two fillers, limestone 2 and natural sand possessed differently charged surfaces, which were very close to isoelectric point. This indicated that they are relatively unstable and can flocculate easily. Upon adding to cement pore solution, stability of the system improved while a charge reversal was observed, attributing to the adsorption of ions from the pore solution onto the surfaces of the filler particle. There, it was found that the dispersing effectiveness by plasticizers can be a factor of both the stability of slurry (magnitude of zeta potential value) and the adsorbed amount of lignosulfonate as described by the change in zeta potentials.

Lastly, in the cement/filler combination system, the adsorption of plasticizers by fillers in presence of cement is dependent on the type of plasticizers present. MapaPlast is adsorbed rapidly by both fillers and cement due to its inherent high negative charge. In the case of SP-130, preferential adsorption appears to favour cement in the presence of limestone 2, whereas competitive adsorption is present when natural sand is mixed with cement. The large zeta potential value of pastes containing MapaPlast as compared to those with SP-130



indicated that the former system is more stable, whereby the tendency to undergo flocculation is lower.

In general, adsorption of plasticizers by the particles – fillers or cement is a rapid process.

**Area 2** – Understanding of the behaviour of SXN in three selected filler obtained from crushed aggregates

Three different fillers; a limestone (different from that from Area 1), an anorthosite and a quartzite were investigated. One plasticizer, SXN was employed here. When the zeta potentials of the fillers were studied alone, all three fillers displayed very different zeta potentials when measured in the cement pore solution. Anorthosite registered a very positive zeta potential of +12.4mV, limestone 0.0mV and quartzite -3.4mV. These results indicate that limestone has the highest tendency flocculate when left alone, whereas anorthosite is the most stable.

When SXN was added, the interaction between the plasticizers and fillers differed. With anorthosite, rapid consumption which plateau at around 0.5%bwoc of SXN added. Limestone is a gradual process with preferential adsorption of polycarboxylate based polymers with shorter side chains, whereas quartzite is more unpredictable in terms of adsorption. However, it seems that quartzite prefer polymers with longer side chain. Stability of the systems is greatest for anorthosite.

## **6.7 Design of a simple and cost-efficient mixer for matrix rheology testing**

### **Abstract**

In a paper by Ng et al. (2014)<sup>40</sup> a novel, simple and cost efficient mixer setup was investigated. The results showed that at the moderate shear rate of 1,850 rpm, the new mixer setup produced matrixes which possessed good homogeneity and flowability, little air entrainment and stable temperature, showing little influence on the heat of hydration of the matrix. This is designed for usage on mixing matrix at lab scale, with the aim to obtain better rheological correlations between the matrix phase and concrete at an affordable price.

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