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# Autogenous deformation and relative humidity Concrete with Aalborg Portland cement and fly ash

COIN Project report 24 - 2010



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FA 3.1 Crack free concrete structures

SP 3.1.1 Early age cracking

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Keywords: Crack-free concrete, autogenous deformation, dilation rigs, relative humidity, measurements systems

Project no.: 3D005930

Photo, cover: «Gallery». © iStock

ISSN 1891–1978 (online) ISBN 978-82-536-1184-6 (pdf)

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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 fulfill 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

Tor Arne Hammer Centre Manager

## Summary

This report summarizes the results from a series of experiments carried out in 7 new dilations rigs measuring autogenous deformation in concrete. The intention was to find a relation between autogenous deformation and relative humidity in three different mixes with three different binders. Another objective was to compare and verify the measurements of the new test rigs with corresponding samples tested according to SINTEF's standardized shrinkage test method, which is described in KS 14-05-04-117.

Three different mixtures were used; one with Portland cement only (Portland cement, class CEM I 52,5 N), one with the same Portland cement and 5,2 % silica by cement weight and the third with the Portland cement and 50 % fly ash by cement weight. Three specimens  $(100\times100\times500 \text{ mm})$  were cast from each mixture; two in the new dilation rigs and one for SINTEF's standard shrinkage test method. In addition, a specimen for measuring relative humidity (% RH) was cast from each mixture. Data from the measurements of deformation and relative humidity at certain concrete ages.

Autogenous deformation was measured with LVDTs (electrical transformers commonly used for measuring linear displacement) in the new Dilation Rigs. To measure relative humidity, a VAISALA Concrete Humidity Measurement System was used. All tests were performed in temperature conditioned environments, and a JULABO FP33 was used to regulate the temperature development in the concrete. Deformation of the reference specimens, were measured by the SINTEF standard shrinkage test method.

Some expected results of the concrete were confirmed during the experiments. Fly ash retards the heat development in the concrete, and further the hardening process. The self-desiccation of the concrete slows down, and seems to result in a higher relative humidity for a longer period.

Considering the results from the new rigs towards the SINTEF standard method, the agreement is very good. However, the new shrinkage test method is still under development, for instance the specific time from which strains should be considered has to be decided. This starting time for zero strain will vary, depending on the rate of the specific concrete mixtures' hardening process. The topic is discussed in the report.

When it comes to the relative humidity measurements, these tests must be regarded as a pilot study where the main goal was to develop the test method and investigate the accuracy of the equipment.

Further experiments, reproducibility test and evaluation must be performed before the methods can be considered as reliable test methods. The project group within COIN will continue the work with other mixtures, and try to improve the test procedure if appropriate.

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## 1 Introduction

## 1.1 Background, [1]

Volume changes in concrete take place during the hardening process through internal factors and through self-desiccation (i.e.exchange of moisture with the surroundings, external factors). This often takes place under some form of restraint, which creates tensile stresses and possible cracking. The consequences may be substantial costs for repairs. The visual impression of the structure may also be challenged, and cracks can compromise the durability of the structure.

Volume changes and cracking tendency may be strongly influenced by the concrete constituents and their volume proportions. The curing conditions are also very important. Many laboratory experiments and experience from real structures have shown that a high curing temperature increases the risk of cracking due to external restraint. Because of this, focus has been directed towards finding new mix proportions and development of new cement types witch induce lower heat generation in the hardening process.

New types of cement and addition of other binder materials require new knowledge of their properties in concrete, with regard to autogenous deformation, thermal properties and mechanical properties. The experiments described in this report are part of a larger project within COIN where the intention is to gather more information about new materials and mix proportion.

## **1.2 Principal objectives and scope**

The objective of the tests described in this report was to investigate the volume changes produced by the concrete itself (autogenous deformation) in concretes made with Portland cement, CEM I 52,5 N (MS/LA/ $\leq$  2) without and with pozzolanic additions of silica fume or fly ash. The objective was to develop a method for relative humidity (% RH) measurements, in order to correlate RH and deformation.

If a relation between autogenous deformation and relative humidity can be determined, it might be possible to predict the remaining shrinkage in a structure by measuring the relative humidity. This can be especially feasible for concrete slabs.

To be able to do all the required measurements, a research group with strong relations to COIN has developed and built a new test-rig for measuring autogenous deformation at isothermal or realistic temperature conditions in concrete. In addition a set-up for measuring relative humidity was used. A pilot project was performed to test and calibrate the rig in May/June 2010. This report describes the first full-scale test-series.

## 2 Materials

## 2.1 Cement

In these experiments a Portland cement; CEM I 52.5 N (MS/LA/ $\leq$  2), Aalborg Rapid, was used. The specification as provided by the manufacturer is provided in Table 1.

| Physical properties                | Specifications         |
|------------------------------------|------------------------|
| 1-day strength                     | 23 MPa                 |
| 2-day strength                     | 35 MPa                 |
| 7-day strength                     | 53 MPa                 |
| 28-day strength                    | 66 MPa                 |
| Setting time                       | 126 minutes            |
| Fineness                           | 442 m <sup>2</sup> /kg |
| Absolute density                   | $3120 \text{ kg/m}^3$  |
| Heat development                   | 356 kJ/kg              |
| α                                  | 1.04                   |
| τ                                  | 12.0 hours             |
| Bogue composition                  |                        |
| C <sub>3</sub> S                   | 62 %                   |
| C <sub>2</sub> S                   | 13 %                   |
| C <sub>3</sub> A                   | 8 %                    |
| C <sub>4</sub> AF                  | 13 %                   |
| Secondary components and additives |                        |
| $SO_3$                             | 3.2 %                  |
| MgO                                | 0.9 %                  |
| Eqv. Na <sub>2</sub> O             | 0.6 %                  |
| Cl                                 | 0.03 %                 |
| Loss on ignition (LOI)             | 2.5 %                  |
| Insoluble residue                  | 0.7 %                  |
|                                    |                        |

 Table 1: Specifications – Cement [2]

## 2.2 Pozzolanic additions

#### Silica fume

Elkem Micro silica Grade 940 Undensified was used in these experiments. Specifications are listed in Table 2.

| Chemical and physical requirements             | Specifications |
|--|----------------|
| SiO <sub>2</sub> (%)                           | > 90           |
| $H_2O$ (moisture content when packed, %)       | < 1,0          |
| Loss on ignition (%)                           | < 3,0          |
| Retained on 45 micron sieve (%)                | < 1,5          |
| Bulk density (when packed, kg/m <sup>3</sup> ) | 200 - 350      |

Table 2: Specifications – Silica fume [3]

## Fly ash

The fly ash was supplied by Norcem (LN21-02). The composition and physical properties are listed in Table 3.

| Chemical and physical requirements | Specifications         |
|------------------------------------|------------------------|
| SiO <sub>2</sub>                   | 54.40 %                |
| Al <sub>2</sub> O <sub>3</sub>     | 22.01 %                |
| Fe <sub>2</sub> O <sub>3</sub>     | 5.83 %                 |
| CaO                                | 4.80 %                 |
| MgO                                | 2.22 %                 |
| K <sub>2</sub> O                   | 2.21 %                 |
| Na <sub>2</sub> O                  | 1.15 %                 |
| С                                  | 3.64 %                 |
| Loss on ignition (LOI)             | 4.08 %                 |
| SO <sub>3</sub>                    | 0.52 %                 |
| Blaine                             | 388 m <sup>2</sup> /kg |
| Specific density                   | $2.20 \text{ g/cm}^3$  |
|                                    |                        |
| Sieve analysis                     |                        |
| 90 [µm]                            | 3.8 % Acc.             |
| 64 [μm]                            | 11.8 % Acc.            |
| 30 [µm]                            | 58.2 % Acc.            |
| 24 [µm]                            | 100 % Acc.             |

Table 3: Composition and physical properties - Fly-ash [4]

## 2.3 Admixtures

## Super plasticizer

A polycarboxylate based super plasticizer, BASF Glenium Sky 552, was used for all mixes. Specifications are listed in Table 4.

| Properties       | Declares values        |
|------------------|------------------------|
| Dry substance    | $(17.5 \pm 1.0)\%$     |
| Density          | $(1.04 \pm 0.02)$ kg/l |
| pH-value         | $6.5 \pm 1.5$          |
| Equivalent Na2O  | < 2.0 %                |
| Chloride content | < 0.01 %               |

 Table 4: Specifications – Super-plasticizer [5]

## 2.4 Aggregates

Each of the concrete mixes contained three fractions of aggregate; one fraction from Årdal (16-24 mm) and two fractions from Svelvik (0-8 and 8-16 mm).

Årdal aggregate is dominated by granite and gneiss, and has an expected E-modulus of 32 GPa. Svelvik aggregate is dominated by gneiss/granite, feldspatic rocks, dark rocks and sedimentary rocks.

Sieve analysis and humidity tests were performed before mixing, and data are included in the proportioning spreadsheets shown in Appendix A1.

## 3 Concrete mixing forms

#### 3.1 Mixture 1, 2 and 3

The mixing forms for mixture 1, 2 and 3 are shown in Table 5, while further details are reported in the proportioning spreadsheets which are included in Appendix A2.

Mixture 2 is a reference mix without pozzolanic materials, while Mixture 1 has a silica/cement ratio of 5.2 % by cement weight and Mixture 3 has a fly ash/cement-ratio of 50 % by cement weight. The mix with 50 % fly ash is expected to have a retarded hardening process, and thereby a lower heat development which might lead to reduced autogenous deformation in the concrete.

| Materials                                   | Mixture 1                      | Mixture 2                      | Mixture 3                      |
|---|--------------------------------|--------------------------------|--------------------------------|
|   | Recipe<br>[kg/m <sup>3</sup> ] | Recipe<br>[kg/m <sup>3</sup> ] | Recipe<br>[kg/m <sup>3</sup> ] |
| $(w/(c + k_s \cdot s + k_{FA} \cdot FA))^1$ | 0.40                           | 0.40                           | 0.45                           |
| Cement                                      | 385                            | 424                            | 250                            |
| Silica fume                                 | 20                             | 0                              | 0                              |
| Fly ash                                     | 0                              | 0                              | 125                            |
| Total quantity of added water               | 180                            | 180                            | 148                            |
| Svelvik gravel 0/8                          | 936                            | 940                            | 940                            |
| Svelvik gravel 8/16                         | 312                            | 314                            | 314                            |
| Årdal gravel 16/24                          | 589                            | 591                            | 591                            |
| Super plasticizer                           | 3.0                            | 3.0                            | 5.0                            |
| s/c   | 5.2 %                          | -                              | -                              |
| f/c   | -                              | -                              | 50 %                           |
| f/b   | -                              | -                              | 30 %                           |

 Table 5: Recipes mixture 1, 2 and 3

<sup>&</sup>lt;sup>1</sup> For these mixtures, the following k-values were used:  $k_s = 2.0$  and  $k_{FA} = 0.4$ 

## 4 Test procedure and equipment

#### 4.1 Mixing and casting

The concrete was mixed in an Eirich paddle mixer with a capacity of 50 litres. The materials were added according to the following procedure:

- 1. Dry mixing 1 min
- 2. Wet mixing 2 min
- 3. Standstill1 min4. Wet mixing2 min
- 4. Wet mixing 2 min

The admixtures were added in step 2, together with the mixing water. Water and admixtures are added within 30 sec.

Slump, air-content and density in the fresh concrete were measured directly after mixing.

From each mixture, two dilatation rig specimens of  $100 \times 100 \times 500$  mm for measuring autogenous deformation and one specimen in a 1 litre plastic bottle for measuring relative humidity were cast. One specimen of  $100 \times 100 \times 500$  mm was cast parallel to this at SINTEF's concrete laboratory for verification of the autogenous deformation results.

## 4.2 Dilatation rigs – Set-up and operational procedures, [6]

The set-up, see Figure 1 and 2, consists of rectangular cuboid moulds which measure  $100 \times 100 \times 580$  mm inside. The moulds are made of 10 mm thick steel plates.

The moulds were internally lined with a layer of adhesive plastic foil and two thin layers of plastic film. Talcum powder was applied between each layer to reduce friction. This makes it possible for the specimen to expand or shrink freely.

The length of the specimens will be 500 mm, and the remaining part of the mould is filled with a piece of extruded polystyrene on each short end. The piece of polystyrene has a whole for LVDTs. LVDT is a type of electrical transformer commonly used for measuring linear displacement. The LVDTs register deformation in the longitudinal direction on each short end of the specimens.

The transmitters are connected to each other with an independent Invar steel bar, and the transmitters are connected with the specimen with Invar pins which goes through the piece of polystyrene and into the specimen.

In addition, each mould is designed with two 6 mm copper pipes on three of the lateral surfaces. These are connected in series to a cooling/heating simulator (Julabo FP33). This is a temperature controlled bath with a pump which provides that a fluid circulates through the rig. Temperature can be regulated from a computer or by manually programming of the bath. In the present test series this simulator circulates water with a temperature of 19.5 °C to control the temperature development in the concrete. The temperature can, however, be altered and more realistic temperature histories can be described and applied to the concrete specimen.

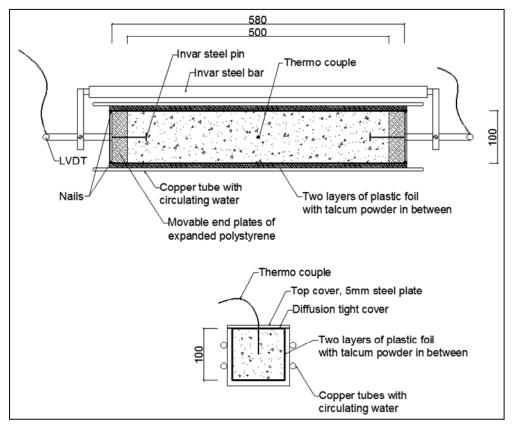


Figure 1: Dilation Rig

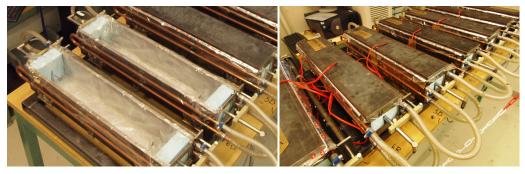


Figure 2: Moulds ready for casting and after covering of specimens

Concretes were cast into the moulds and compressed by hand, using a casting ladle. After compaction, the concrete surfaces were covered with plastic film, then an aluminium foil and detached a 5 mm thick steel plate to keep the plastic/aluminium foil sealing in place. A thermo couple was put centrically into each specimen through the top steel plate.

Once the hardening of the concrete was initiated, the piece of extruded polystyrene was liberated in the longitudinal direction by removing two nails on each short end of the mould. This was done to ensure freely movement of the specimens. At this time the LVDTs were reset as well.

The rig stood in a conditioning room which was set to hold 20  $^{\circ}$ C and 50 % relative humidity. Instruments for measuring temperature and relative humidity in the room were used to record the conditions in the room.

## 4.3 Control measurements

For verifications of the test results in the dilation rigs, an extra  $100 \times 100 \times 500$  mm specimen was cast from each mixture. This was tested in SINTEFs concrete laboratory according to procedure KS 14-05-04-117, which describes a method for measuring drying shrinkage of hardened concrete, but in this case the specimens were sealed to measure autogenous deformation.

For this method, the concrete was cast into moulds with special measurement studs (20 mm) placed centrically in each short-end. The concrete was filled into the mould in two layers, and each layer was compacted by hand, using a casting ladle. Extra attention is paid around corners, along edges and around the knobs during compaction.

The surface of the prisms were covered with plastic and stored in the laboratory at  $20 \pm 4^{\circ}$ C until demoulding at an age  $22 \pm 2$  hours. The specimens were then sealed in plastic and aluminium foil to avoid external drying and marked with ID and an arrow to indicate which end should point upwards when measuring the length. One must also make sure that the knobs are fixed to the specimens.

The prisms were stored in a conditioning room at  $20 \pm 2$  °C and 50 % relative humidity. Length and weight of the specimens were measured at 1, 5, 8, 11 and 20 day's age.

The following exception from the procedure was made to achieve approximately equal conditions for the control prisms as for the specimens in the dilation rig:

• The specimens were not stored in water for 7 days before placing in the conditioning room. Instead, they were placed directly in the room after demoulding and packing.

## 4.4 Relative humidity in concrete, [7]

From each mixture a specimen was cast in a closed plastic bottle (1 litre Nalgene bottle) for measuring relative humidity (% RH) in the concrete parallel to the deformation and temperature measurements, see Figure 3.

A plastic tube with a diffusion open tape in the bottom was cast into each bottle. The end of the tube was approximately 6.5 cm down in the specimen. Afterwards the bottles were sealed with a perforated lid, in such a way that the pipe went through. Putty was used to seal the top of the pipes carefully.

% RH was measured with a Vaisala HM44 Concrete Humidity Measurement System. In addition to measuring relative humidity, the sensors also measure temperature inside the specimens. The following accuracy for the sensors are given by the producer(the sensors are calibrated at delivery);

| 0-90 % RF         | $\rightarrow \pm 2 \% RF$                |
|-------------------|--|
| 90-100 % RF       | $\rightarrow \pm 3 \% RF$                |
| Accuracy at 20 °C | $\rightarrow \pm 0.4 \ ^{\circ}\text{C}$ |

Before each measurement, the tube sealing was removed, and the sensors were immediately placed into the plastic tubes. They were left in the tubes 30 minutes before the RH-values were recorded. According to the producer, 30 minutes is a minimum time period to ensure that RH has stabilized. It was also argued that there is a certain risk of drifting of the sensors if they are exposed to high values of relative humidity for a longer period. Because of this,

the sensors were removed after each measurement. The specimens were stored in 20  $^{\circ}$ C and 50  $^{\circ}$ RH climate during the test period.

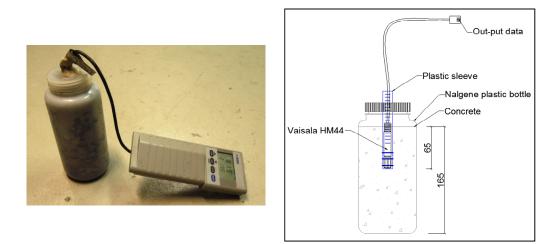


Figure 3: Specimen for RH-measurements

To verify the measured RH-values, the Vaisala sensors were calibrated a few times during the test period. The calibration is performed in sealed containers with different salt solutions inside. Depending on the salt used, the air above the salt solution will reach a certain relative humidity at a certain temperature. The calibration equipment is shown in Figure 4, and data for the selected salt solutions are given in Table 6. The calibration was performed at  $23 \pm 0.5$  °C and  $50 \pm 2$  % RH.



Figure 4: Equipment for calibrating Vaisala sensors

| Salid phase | % Humidity at Specified Temperatures |       |       |       |
|-------------|--------------------------------------|-------|-------|-------|
| Solid phase | 10 °C                                | 20 °C | 25 °C | 30 °C |
| KNO3        | 95                                   | 93    | 92.5  | 91    |
| NaCl        | 76                                   | 75.7  | 75.3  | 74.9  |
| $K_2SO_4$   | 98                                   | 97    | 97    | 96    |

Table 6: Humidity at specified temperatures for selected salt solutions

## 5 Test results

#### 5.1 Curing conditions

The rig was placed in a conditioning room which was planned to hold 20 °C and 50 % RH. However, a stable temperature and humidity level was not achieved. The room temperature was held with an accuracy of  $20 \pm 2$  °C, with a deviation after approximately 120 hours when the conditioning system was out of function during the weekend. RH was held at  $50 \pm 15$  %. Work will continue to improve the stability. Variations in the relative humidity did probably not affect the concrete much, since the prisms were stored in closed system. However, the temperature variations will influence the measured deformations because the LVDT's are placed outside the specimens and are exposed to a temperature history which differs from the concrete.

Figure 5 shows measured values for concrete temperatures inside the specimens as well as temperature and relative humidity in the room during the test period of 480 hours. Figure 5 shows variations of the concrete temperature from 19.5 °C for mixture 2 to 20.5 °C for mixture 3. The thermo couples were not calibrated in the experiment, and this may explain the variations in temperature between the three mixtures. For future experiments a calibration of the thermo elements should be done.

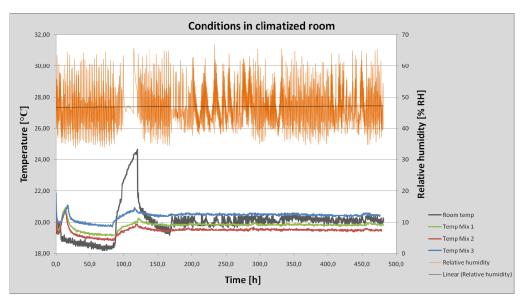


Figure 5: Temperature and relative humidity in the conditioning room

## 5.2 Fresh concrete properties

The results from testing of the fresh concrete are given in Table 7. Time after addition of water is given in parenthesis. Fresh properties were not the main issue for these tests, and no further comments are included in this report.

| Fresh concrete              | Mixture 1     | Mixture 2     | Mixture 3     |
|-----------------------------|---------------|---------------|---------------|
| Slump [mm]                  | 210 (10 min)  | 210 (13 min)  | 250 (12 min)  |
| Slump Flow [mm]             | -             | -             | 620 (12 min)  |
| Air-content [%]             | 2.8 (20 min)  | 1.7 (23 min)  | 0.9 (22 min)  |
| Density[kg/m <sup>3</sup> ] | 2430 (18 min) | 2460 (21 min) | 2450 (20 min) |

**Table 7: Fresh concrete properties** 

#### 5.3 Relative humidity

Table 8 to 10 show the results from the RH-measurements (calibrated values) inside the plastic bottles for Mixture 1-3. The values are also shown in Figure 6, together with the temperature curves from the dilation rig.

| Conc | rete age | Sensor No. | RH in concrete | Temperature [°C] |
|------|----------|------------|----------------|------------------|
| [h]  | [days]   |            | [%]            |                  |
| 121  | 5        | 14         | 74.2           | 21.9             |
| 144  | 6        | 14         | 80.5           | 19.4             |
| 169  | 7        | 14         | 83.6           | 18.8             |
| 482  | 20       | 6          | 67.5           | 19.3             |
| 488  | 20       | 6          | 69.0           | 20.1             |

Table 8: % RH Mixture 1 (silica fume)

| Conc | rete age | Sensor No. | RH in concrete | Temperature [°C] |
|------|----------|------------|----------------|------------------|
| [h]  | [days]   |            | [%]            |                  |
| 120  | 5        | 6          | 80.5           | 22.0             |
| 141  | 6        | 6          | 84.7           | 19.5             |
| 166  | 7        | 6          | 86.7           | 18.9             |
| 479  | 20       | 1          | $(52.5)^2$     | 19.4             |
| 485  | 20       | 1          | $(54.5)^2$     | 19.7             |

Table 9: % RH Mixture 2 ("reference")

| Conc | rete age | Sensor No. | RH in concrete | Temperature [°C] |
|------|----------|------------|----------------|------------------|
| [h]  | [days]   |            | [%]            |                  |
| 117  | 5        | 1          | 88.5           | 22.0             |
| 139  | 6        | 1          | 90.0           | 19.5             |
| 164  | 7        | 1          | 92.0           | 19.0             |
| 477  | 20       | 2          | 92.0           | 19.4             |
| 483  | 20       | 2          | 92.0           | 19.5             |

Table 10: % RH Mixture 3 (Fly ash)

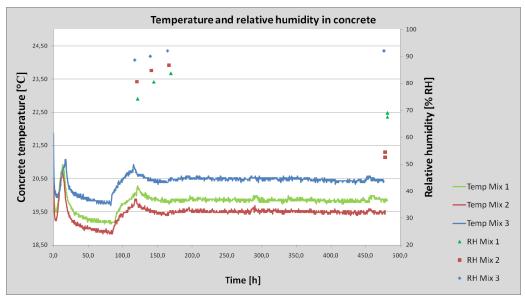


Figure 6: Relative humidity and temperature in Mixture 1, 2 and 3

<sup>&</sup>lt;sup>2</sup> The calibrated values had large deviation from non-calibrated values for this individual test. The reason for this is unknown and the values might not be reliable.

As can be seen in the tables 8 to 10 and in figure 6, mixture 3 deviated from the other two mixes by maintaining a high value of relative humidity during the whole test period. The deviating behaviour of Mix 3 is probably due to the added fly-ash. Fly ash retards the heat development in the concrete, as well as the hardening process. The self-desiccation of the concrete thus slows down, contributing to a higher relative humidity for a longer period.

Both mixture 1 and 2 had a clear decrease of % RH towards the end of the test period, which was larger than expected. Experiments on similar concretes with Standard FA cement and v/c=0.4 have shown a decrease from 97 to 89 % RH during the first 20 days [8]. That gives an 8 % decrease, while the values for mixture 1 and 2 indicate a 15 to 30 % reduction in % RH during the 20 days test period, which is extraordinary large.

The values also indicate that there is an increase of % RH in the beginning of the test period for all mixes. This is not in agreement with experience from previous experiments and common knowledge. % RH normally starts at a high value, and decreases as the concrete hardens. This error can be related to the increase in room temperature between 90 and 100 hours, see figure 5. The temperature increase did not last long enough for the concrete to stabilize on a higher temperature. Thus, the sensors, which were stored in the room, held a temperature of approximately 4 °C higher than the average concrete temperature. When inserting the sensors (24 °C) into the specimens (20 °C), it might have lead to a heating of the cavity in the concrete, and further resulting in lower RH-value measurements.

In this experiment, the relative humidity was recorded after storing the sensors in the specimens for 30 minutes. According to the producer, this should be enough. However, experience from other experiments and unpublished work has shown that the sensors must be left in the specimens for 4-6 days for the relative humidity to stabilize. This might be because the concrete surface in the hole is exposed to some drying when inserting or removing the sensors. The concrete needs time to compensate for this drying and restore a relative humidity in the small hole which should be representative for the whole specimen. The values measured after 30 minutes might be 5-10 % lower than the values measured after 6 days. According to the Swedish council of construction industry, RBK [9], measurements with Vaisala sensors should not occur until 12 hours after installation for v/c > 0.4 and 48 hours for v/c < 0.4. This is in agreement with experience from this project.

The values in the last column of the tables 8 to 10 are temperatures measured inside the specimens with the Vaisala sensors. These values show some variations between the three mixtures at the same measuring point, but this is most likely related to calibration of the sensors and not temperature differences between the three specimens.

For further experiments the sensors should be left in the specimens during the whole test period, and only removed for short periods when calibration is necessary. In addition, control measurements of RH on crushed specimens put on glass tubes should be performed at specific time intervals on parallel specimens. Unpublished results have shown that the RH-values for crushed concrete can be 2-6 % higher, depending on the v/b-ratio. In addition, the sensors should be calibrated with regard to temperature together with the calibration of relative humidity.

#### 5.4 Autogenous deformation, [10]

Defining the setting time zero for a certain concrete is one of the main issues when it comes to understanding autogenous deformation in concrete. Earlier experiments have shown that the parameter time zero,  $t_0$ , is difficult to detect through indirect methods such as early heat liberation,  $t_{Q=12kJ}$ . Setting according to heat is experienced to be around 2-3 hours earlier than setting according to semi-adiabatic tests in e.g. a TSTM rig. An appropriate  $t_0$  for stress calculations has shown to be the point in time where the TSTM has developed 1/10 of the maximum compressive strength during the heating period.

Earlier experiments where  $t_0$  was determined in a TSTM rig showed that  $t_0$  increased from 13 hours to 15 hours when the fly ash content increased from 0 to 35 %. Silica fume (Mix 1) has been shown to shorten  $t_0$ . If this is taken into consideration in these experiments performed in the dilation rig, one can assume the following time zero for the three mixtures:

| Mixture 1 | $t_0 = 9$ hours  |
|-----------|------------------|
| Mixture 2 | $t_0 = 11$ hours |
| Mixture 3 | $t_0 = 13$ hours |

The deformation measurements in the dilation rigs were initiated 5-6 hours after casting. This is long before final set and therefore the "semi-plastic" phase is part of the first hours of all curves. The average autogenous deformation results for each of the three mixtures are shown in Figure 7. Further, the values for the SINTEF reference prisms are included. Concrete temperature and RH-values are plotted on the secondary axis.

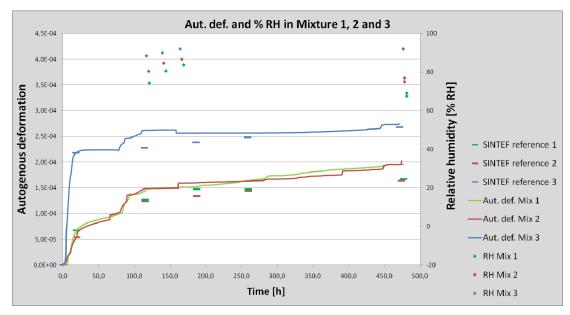


Figure 7: Autogenous deformation and % RH – Mixture 1, 2 and 3

When the measured strains are gathered in Figure 7, it seems that the autogenous shrinkage was largest for mixture 3 which contains a large amount of fly-ash. This is not in agreement with general knowledge and is due to the unclear definition of the time zero for measurement start. The general knowledge is that concrete containing FA develops less autogenous shrinkage than other concrete.

If it is assumed that  $t_0 = 9$  hours for all three mixtures, the development will be as shown in Figure 8.

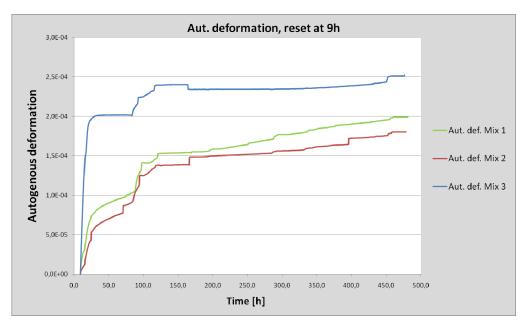


Figure 8: Autogenous deformation,  $t_{\theta} = 9$  hours

Figure 9 shows curves where  $t_0$  is set to 9, 11 and 13 hours for Mixture 1, 2 and 3, respectively. This probably gives a more correct picture of the development of autogenous deformation. However, regardless of time zero, the results show that Mixture 3 has the highest autogenous deformation the first 20 hours.

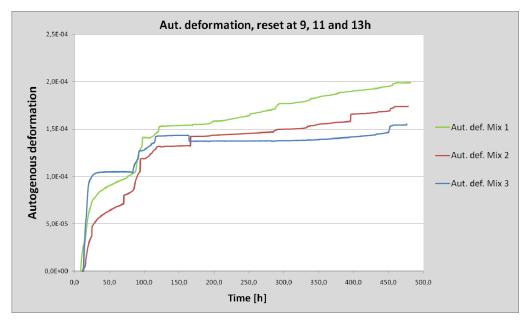


Figure 9: Autogenous deformation,  $t_0 = 9$ , 11 and 13 hours

The first measurements for the SINTEF reference prisms were performed after 24 hours. For comparison, the starting-point for the control prism curves is set to be the 24h-value for the corresponding Dilation rig curve. This is shown in Figure 10.

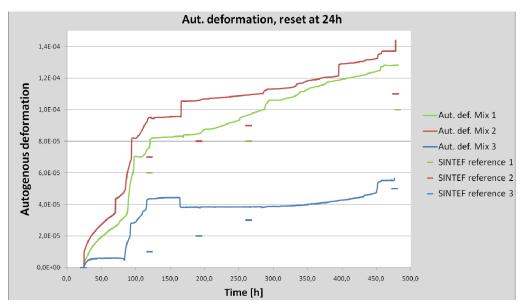


Figure 10: Autogenous deformation, t0 = 24 hours, comparison with SINTEF reference

When the strain development after 1 day is compared, it is seen that fly-ash concrete has the lowest shrinkage. While mixture 1 has approximately  $170 \cdot 10^{-6}$  after 3 weeks, mixture 2 has  $140 \cdot 10^{-6}$  while mixture 3 has only  $60 \cdot 10^{-6}$ . This means that the fly ash concrete might be less vulnerable to shrinkage cracking than the two other mixtures.

Considering the results from the new dilation rigs and the SINTEF standard method, the agreement is very good; all final results are within limits of  $\pm 25 \cdot 10^{-6}$  (micro strains). This confirms the first experiments with the new rigs.

As can be seen in figure 7 to 10, the curves are not very smooth. They include some jumps which are not related to material behaviour. This can be explained by external influence on the rig, i.e. temperature increase or touching of the rig, or because of internal friction and holding of the LVDTs. For later experiments actions should be taken to reduce this.

Approximately 80 hours after casting, accelerated strain development (contraction) seemed to occur in all the specimens in the new test rig. Corresponding behaviour was not seen in the specimens for the SINTEF method. The explanation may be due to the uncontrolled variation in room temperature seen in figure 5. The concrete is isothermal while the measuring equipment is affected by the room climate.

## 6 Conclusions

The procedure for measuring relative humidity in "fresh" concrete is still under development, and there are great uncertainties attached to the presented results. The relatively irregular results are related to the test procedure, and the results can not be regarded as reliable. However, these experiments have been an important step on the road to find a reliable test procedure to measure relative humidity in concrete.

Because of the difficulties with the RH-measurements mentioned above, it is impossible to draw any conclusions on the relation between relative humidity and autogenous deformation in concrete at this stage.

If we study the strain development beyond 1 day, it is seen that fly-ash concrete has the lowest shrinkage. The same is valid if one assumes  $t_0 = 9$ , 11 and 13 hours for the three mixtures.

For later experiments a method for determine setting time zero must be used. In addition to the TSTM method mentioned in chapter 5, a temperature criterion can be used;  $t_0$  can be determined according to a 2 °C/12kJ criteria + 2 hours by use of a calorimeter [11].

The agreement between the SINTEF test method and the results from the new dilation rigs seems to be rather good. If one exclude the apparent increase of shrinkage at the point in time where the room temperature increases, the autogenous deformation measured with the two test methods gives overall a reasonably good correspondence. The present results have pointed out the need for further work on test set-ups and climate control.

## 7 Recommended further research

For further research, focus should be aimed towards the following topics:

- Develop a criterion for the zero-point for deformation curves for example according to the temperature criteria 2 °C/12kJ criteria + 2 hours.
- Work to improve the climatic conditions in the test room to get a more stable temperature to avoid the T-disturbance of the LVDTs.
- Increase the conditioning room RH to reduce the RH-difference between specimens and air.
- Work to improve the reliability of the relative humidity measurements to be able to map the relation between autogenous deformation and % RH.
- Investigate and map the influence of the concretes temperature history on autogenous deformation.
- Perform experiments to measure the long time deformation development, for instance during 6 months.

## 8 Acknowledgement

The new Dilation Rigs could not have been developed and built without good support from and co-operation with all the contributors in this COIN Project 3.1. We want to thank NTNU, SINTEF, Skanska, The Norwegian Public Roads Administration, Unicon and Norcem for participating. Special thanks to Ove Loraas and Steinar Seehuus at NTNU who have produced the rig, and to Lars Haugan, SINTEF, who was responsible for pilot tests and initialisation of the tests described in this report.

## References

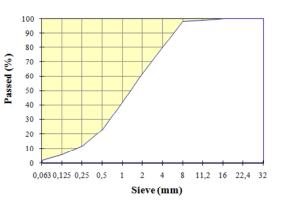
- 1. Bjøntegaard Ø. (2009) Volume changes and cracking tendency in concrete. Technology report no. 2565, Norwegian Public Roads Administration, Road Directorate. 2009-09-07, ISSN 1504-5005
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- 11. Bjøntegård, Ø., Kanstad, T., Sellevold, E.J.,(2000), *t0 The startpoint of stress calculations*, in IPACS TASK 2 + 3 Memo meeting in Delft 20-21 March.

## Appendix A1

#### Aggregate – Fraction I

| Type: | Svelvik 0/8 |
|-------|-------------|
| Date: | 2009-10     |
| FM =  | 3,29        |

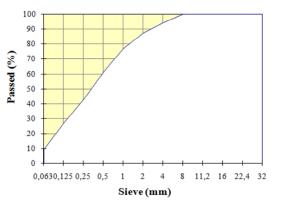
|        |           |           | Sieve   |        |
|--------|-----------|-----------|---------|--------|
| Sieve  | Sieve res | sidue (g) | residue | Passed |
|        | 1         | 2         | (%)     | (%)    |
| 32     | 0         | 0         | 0,0     | 100,0  |
| 22,4   | 0         | 0         | 0,0     | 100,0  |
| 16     | 0         | 0         | 0,0     | 100,0  |
| 11,2   | 10,5      | 10,5      | 1,0     | 99,0   |
| 8      | 17,5      | 17,5      | 1,7     | 98,3   |
| 4      | 195,7     | 195,7     | 19,6    | 80,4   |
| 2      | 378,1     | 378,1     | 37,8    | 62,2   |
| 1      | 579       | 579       | 57,8    | 42,2   |
| 0,5    | 768,2     | 768,2     | 76,7    | 23,3   |
| 0,25   | 881,6     | 881,6     | 88,1    | 11,9   |
| 0,125  | 940,3     | 940,3     | 93,9    | 6,1    |
| 0,063  | 980,0     | 980,0     | 97,9    | 2,1    |
| Bottom | 1001      | 1001      |         |        |



#### Aggregate – Fraction II

| 00 0  |              |
|-------|--------------|
| Type: | Svelvik 8/16 |
| Date: | 2009-10      |
| FM =  | 1 74         |

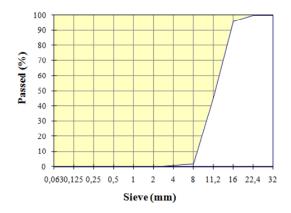
|        |           |           | Sieve   |        |
|--------|-----------|-----------|---------|--------|
| Sieve  | Sieve res | sidue (g) | residue | Passed |
|        | 1         | 2         | (%)     | (%)    |
| 32     | 0         | 0         | 0,0     | 100,0  |
| 22,4   | 0         | 0         | 0,0     | 100,0  |
| 16     | 0         | 0         | 0,0     | 100,0  |
| 11,2   | 0         | 0         | 0,0     | 100,0  |
| 8      | 0         | 0         | 0,0     | 100,0  |
| 4      | 29,2      | 28,8      | 5,8     | 94,2   |
| 2      | 63,9      | 62,4      | 12,7    | 87,3   |
| 1      | 115,4     | 115       | 23,1    | 76,9   |
| 0,5    | 191,9     | 193,4     | 38,6    | 61,4   |
| 0,25   | 282,6     | 285,1     | 56,9    | 43,1   |
| 0,125  | 362       | 364       | 72,8    | 27,2   |
| 0,063  | 449       | 454       | 90,6    | 9,4    |
| Bottom | 498       | 499       |         |        |



#### Aggregate – Fraction III

| 00             | <u> </u> |             |
|----------------|----------|-------------|
| Type:<br>Date: |          | Årdal 16/24 |
| Date:          |          | 2008-11-21  |
| FM =           |          | 6,51        |

| Sieve  | Sieve res | sidue (g) | Sieve<br>residue | Passed |
|--------|-----------|-----------|------------------|--------|
|        | 1         | 2         | (%)              | (%)    |
| 32     | 0         | 0         | 0,0              | 100,0  |
| 22,4   | 0         | 0         | 0,0              | 100,0  |
| 16     | 3         | 5         | 4,0              | 96,0   |
| 11,2   | 55        | 54        | 54,5             | 45,5   |
| 8      | 98        | 98        | 98,0             | 2,0    |
| 4      | 99        | 99        | 99,0             | 1,0    |
| 2      | 100       | 100       | 100,0            | 0,0    |
| 1      | 100       | 100       | 100,0            | 0,0    |
| 0,5    | 100       | 100       | 100,0            | 0,0    |
| 0,25   | 100       | 100       | 100,0            | 0,0    |
| 0,125  | 100       | 100       | 100,0            | 0,0    |
| 0,063  | 100       | 100       | 100,0            | 0,0    |
| Bottom | 100       | 100       |                  |        |



Appendix A2

| Value         K           Value         K           %         0.40         -           %         0.40         -           %         0.2         0.00           %         0.2         0.00           %         0.2         0.00           %         %         %   |  | ĺ                      |                      |                          |                     |     | I  |
|--|--|------------------------|----------------------|--------------------------|---------------------|-----|----|
| Value         k           %1         0.40         -           %3         0.0         0.40           %3         0.0         0.40           %3         1.5         -           %3         1.5         -           %3         5.2         0.00           %3         0.00         0.00           %3         0.00         0.00           %4         1.5         -           %4         0.00         0.00           %5         0.00         0.00           %6         %8         -           %4         %9         -           %4         %9         -           %6         %6         %6           %6         %6         %6           %9         0.0         0.0           936.5         2.34         2.34           110.7         117.7         117.7           %9         0.0         0.0         0.0           936.5         2.34         2.34           539.4         17.7         14.7           %9         0.0         0.0         0.0           0.0         0.0         0.   |  |                        |                      |                          |                     | nem | Mi |
| %i         0.40         -           %i         5.2         200           %i         0.0         0.0           552         0.73         0.00           552         0.79         0.00           552         0.79         0.00           552         0.79         0.00           552         0.79         0.00           900         0.00         0.00           0         0         0           0         0         0           0         0         0           0         0         0           0         0         0           0         0         0           0         0         0           0         0         0           0         0         0           11/m <sup>1</sup> 352           11/m <sup>1</sup> 14/7           11/m <sup>1</sup> 14/7           11/m <sup>1</sup> 14/7           11/m <sup></sup>  |  | Company                |                      | Date                     |                     | ts: | xt |
| %         5.2         2.00 $0.40$ $%$ $1.5$ $2.0$ $0.40$ $%$ $1.5$ $0.00$ $0.00$ $0.00$ $%$ $0.00$ $0.00$ $0.00$ $0.00$ $%$ $0.00$ $0.00$ $0.00$ $0.00$ $%$ $0.00$ $0.00$ $0.00$ $0.00$ $%$ $0.00$ $0.00$ $0.00$ $0.00$ $0.00$ $0.00$ $0.00$ $0.00$ $0.00$ $%$   | Lars Haugan SINT   | SINTEF Byggforsk       |                      | 2010-06-0                | 12                  |     | u  |
| %1         0.0         0.40           115         -         -           552         0.79         0.00           552         0.79         0.00           552         0.00         0.00           562         0.00         0.00           51         0.00         0.00           552         0.00         0.00           0.00         0.00         0.00           0.00         0.00         0.00           0.00         0.00         0.00           0.00         0.00         0.00           0.00         0.00         0.00           1         252           1         233           2         234         234           2         23,4         23,4           2         23,4         23,4           2         23,4         23,4           2         23,4         23,4           2         23,4         23,4           2         23,4         23,4           2         23,4         23,4           2         0,0         0,0           0         0,0         0,0         0,0  |  |                        |                      |                          |                     |     | re |
| 1.5         . $1.5$ $0.00$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$ $0.00$ $0.0$ $0.0$   | Material   |                        | 0 Dry conte Alkalies | e Alkalies               | Chlorides           |     | 1  |
| 119)         % ark C         % ark S         %         |  | 0                      | [%]                  | [%]                      | [%]                 |     |    |
| 113)         0.00         0.00           552         0.79         0.00           0.00         0.00         0.00           0.00         0.00         0.00           0.00         0.00         0.00           11m <sup>1</sup> 352           11m <sup>1</sup> 293           11m <sup>1</sup> </td <td>Aalborg Rapid</td> <td>3160</td> <td>•</td> <td>00'0</td> <td>00'0</td> <td></td> <td></td>  | Aalborg Rapid  | 3160                   | •                    | 00'0                     | 00'0                |     |    |
| 552         0.79         0.00         0.00           0         0         0.00         0.00           0         0         0.00         0.00           0         0         0         0           0         0         0         0           1         1         352           1         1         352           1         1         352           1         1         352           1         1         352           1         1         352           1         1         353           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1           1         1         1   | Silika   | 2200                   | 100                  | 0,00                     | 0,00                |     |    |
| 0.00         0.00         0.00           0.00         0.00         0.00           0.00         0.00         0.00           0.01         0.00         0.00           0.01         0.00         0.00           1         352         1           1         352         1           1         299         1           1         233         1           2         34,6         0,3           1         167,7         4,2           1         167,7         4,2           1         167,7         4,2           1         14,7         14,7           1         14,7         14,7           1         14,7         14,7           0         0,0         0,0         0,0           0         0,0         0,0         0,0           0         0,0         0,0         0,0           0         0,0         0,0         0,0           0         0,0         0,0         0,0           0         0,0         0,0         0,0  | Aalborg White  | 3160                   | 100                  | 0,00                     | 0,00                |     |    |
| 0.00         0.00         0.00           vol%         0.0         0.0           vol%         0.0         0.0           verdi         0.0         0           verdi         352         1           verdi         0.31         1           0.31         299         1           verdi         299         1           verdi         299         1           verdi         293         1           116/1         0.0         0.0         0           116/1         14,7         14,7         14,7           116/1         14,7         14,7         14,7           116/1         0,0         0,0         0,0         0           0         0,0         0,0         0,0         0         0           0         0,0         0,0         0,0         0         0         0           114,7         14,7         14,7         14,7         14,7         14,7  | BASF Micro Air 110 (1:19)  | 1084                   | •                    | 00.00                    | 0.00                |     |    |
| vol %         vol %           0.0         0.0           0.1         0.0           0.1         252           1/m <sup>1</sup> 352           1/m <sup>1</sup> 255           1/m <sup>1</sup> 255           1/m <sup>1</sup> 259           1/m <sup>1</sup> 259           1/m <sup>1</sup> 259           1/m <sup>1</sup> 259           1/m <sup>1</sup> 295           1/m <sup>1</sup> 293           281         4           0.31         0.31           Named <sup>-</sup> CMN         Named <sup>-</sup> CMN           167         0         0.0           167         0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.0         0.0         0.0           0.00         0.00         0.00  | BASF Glenium SKY 552   | 1040                   | 17.5                 | 0.00                     | 0.00                |     |    |
| 00         00           e [lim <sup>1</sup> ]         352           e [lim <sup>1</sup> ]         0.31           c [lim <sup>1</sup> ]         0.31           e [lim <sup>1</sup> ]         0.00         0.00           e [lim <sup>1</sup> ]         0.00         0.00           e [lim <sup>1</sup> ]         0.00         0.00           e [lim <sup>1</sup> ]         0.00 |  | 1200                   | •                    | 0.00                     | 0.00                |     |    |
| 0.0         0.0           verdi         293           0.11         352           0.11         322           0.11         322           0.11         323           0.11         323           0.11         323           0.11         239           0.11         239           0.11         0.31           National Activitient         Marted Activitient           167.7         4.2         4.2           0.0         0.0         0.0         0.0           1167.7         4.2         4.2           1167.7         4.2         4.2           1167.7         4.2         4.2           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0           0.00         0.00         0.00         0.00   |  | 1000                   | 6                    | 000                      | 000                 |     |    |
| Vertit         Vertit           e [l/m <sup>3</sup> ]         352           9 [l/m <sup>3</sup> ]         299           0.31         Set "Achievel" = "Warned": Critin           Increte         Wanted Achievel" = "Warned": Critin           167,7         4,2         4,2           0,0         0,0         0,3         0,3           166,7         4,2         4,2         4,2           167,7         4,2         4,2         4,2           167,7         4,2         4,2         4,2           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,00         0,00         0,00         0,00         0,00  | Steel fibre  | 7800                   | , ,                  | -                        | -                   |     |    |
| Imm <sup>1</sup> 352           ** [timm <sup>1</sup> 352           1 [timm <sup>1</sup> 352           9 [timm <sup>1</sup> 352           9 [timm <sup>1</sup> 352           9 [timm <sup>1</sup> 299           9 [timm <sup>1</sup> 299           9 [timm <sup>1</sup> 299           8 [timm <sup>1</sup> 299           8 [timm <sup>1</sup> 299           8 [timm <sup>1</sup> 291           1 2 [timm <sup>1</sup> 9 [timm <sup>1</sup> 1 2 [timm <sup>1</sup> 9 [timm <sup>1</sup> 1 2 [timm <sup>1</sup> 9 [timm <sup>1</sup> 1 1 2 [timm <sup>1</sup> 9 [timm <sup>1</sup> 1 1 2 [timm <sup>1</sup> 1 1 2 [timm <sup>1</sup> 1 1 2 [timm <sup>1</sup> 2 3 4 2           1 1 3 7         1 1 3 7           1 2 3 3 5 5         7 3 4 2           2 3 4 7         7 3 4 7           0 0 0         0 0 0         0 0           0 0 0         0 0 0         0 0           0 0 0         0 0         0 0           0 0 0         0 0         0 0           0 0 0         0 0         0 0           0 0 0         0 0         0 0   | PP-fibre   | 1000                   |                      |                          |                     |     |    |
| Milmini         352           0[Imini         299           0.31         299           norm         0.31           Name         Kachievel           384,6         9,6           20,0         0,0           0,0         0,0           12,6         9,6           12,6         0,5           12,6         0,3           12,6         0,3           12,6         0,3           12,6         0,3           12,6         0,3           12,6         0,3           12,6         0,3           12,6         0,3           11,7         11,7           11,7         11,7           11,4,7         11,7           0,0         0,0           0,0         0,0           0,0         0,0           0,0         0,0           0,0         0,0           0,00         0,00           0,00         0,00           0,00         0,00           0,00         0,00   |  |                        |                      |                          |                     |     |    |
| [IIIm]         299           not         0.31           Set "Achieved" = "Warnbed": CHIN           Increte         Set "Achieved" = "Warnbed": CHIN           Nanted Achieved         Set "Achieved" = "Warnbed": CHIN           ncrete         384,6         9,6         9,6           20,0         0,0         0,5         0,5         0,5           10,7         0,0         0,0         0,0         0,0         0,0           112,6         0,3         14,7         14,7         14,7         14,7           112,5         7,8         7,8         7,8         7,8         14,7         14,7           114,7  | For cement, pozzoian sog tillers density is stated tor ory materials.<br>For admixtures wet density is stated. | / IS Stated for dry ma | atenais.             |                          |                     |     |    |
| 0.31   |  |                        |                      |                          |                     |     |    |
| Rayman         Set "Achieved" = "Warmed"", CMIN           Increte         Warted Achieved" = "Warmed", CMIN           Nature         Kgim³         Set "Achieved" = "Warmed", CMIN           107         Kgim³         Kgim³         Set "Achieved" = "Warmed", CMIN           384,6         9,6         9,6         9,6         9,6         9,6           117,7         4,2         4,2         4,2         4,2         4,2         4,2         1,4,7         1   |  |                        |                      |                          |                     |     |    |
| Set: Achievet" = "Warned": CHN           Narred": CHN           Narred": CHN           Set: Achievet" = "Warned": CHN           Satis         Set: Achievet" = "Warned"           Satis         Satis         Satis           Satis         Satis         Satis         Satis           Satis <ths< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td></ths<>   |  |                        |                      |                          |                     |     |    |
| Ortioned concrete           Sortioned concrete           als         kg/m³         kg/m³<  |  |                        |                      |                          |                     |     |    |
| Sortuoned concrete         kg/m³         kg/m³         kg/m³         kg         kg <t< td=""><td></td><td></td><td>Reset oo</td><td>Reset correction; Ctrl K</td><td></td><td></td><td></td></t<>  |  |                        | Reset oo             | Reset correction; Ctrl K |                     |     |    |
| iats         kgim*         kg         kg         kg           'g Rapid         384,6         9,6         9,6         9,6         9,6           'g White         0.0         0.0         0.0         0.0         0.0         0.0           'g White         0.0         0.0         0.0         0.0         0.0         0.0           'g White         0.20,0         0.0         0.0         0.0         0.0         0.0           alter         15,7         4,2         4,2         4,2         4,2         4,2         14,7         14,   | Fresh concrete   | [                      |                      |                          | UOII:               |     |    |
| G Rapid         384,6         9,6         9,6         9,6           0         0,7         0,5         0,5         0,5         0,5           0         10,7         0,0         0,0         0,0         0,5         0,3           atter         10,7         4,2         4,2         4,2         4,2         4,2           bed water         12,6         0,3         0,3         0,3         0,3         0,3           c0/8         312,5         7,8         7,8         7,8         7,8         7,8           c0/8         312,5         7,8         7,8         7,8         7,8         7,8           c0/16         312,5         7,8         7,8         7,8         7,8         7,8           c0/16         312,5         7,8         7,8         7,8         7,8         7,8           c0/16         0,0   |  |                        | corr.air             | corr.dens                | corr.dens corrected |     |    |
| QMhte         20,0         0,5         0,6         0,0<  |  | 0'0                    | 0;0                  | 0'0                      | 384,6               |     |    |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$  | ()   | 25,0                   | 0'0                  | 0'0                      | 20,0                |     |    |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$  | Air content (%)  | 5                      | 0'0                  | 0,0                      | 0,0                 |     |    |
| 12,6         0.3         0.3         0.3           936,5         23,4         23,4         23,4           312,5         7,8         7,8         7,8           589,4         14,7         14,7         14,7           589,4         14,7         14,7         14,7           589,4         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,00         0,0         0,0           0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00   | (kg/m³)  | 2424                   | 0'0                  | 0'0                      | 167,7               |     |    |
| 936,5         23,4         23,4           312,5         7,8         7,8           589,4         14,7         14,7           589,4         14,7         14,7           589,4         0,0         0,0           0         0,0         0,0         0,0           0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           3,0,0         0,00         0,00         0,0           0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00  |  | 395                    | 0'0                  | 0'0                      | 12,6                |     |    |
| $\begin{array}{ c c c c c c c c c c c c c c c c c c c$   |  | 1                      | 0.0                  | 0.0                      | 936,5               |     |    |
| 589.4         14,7         14,7         14,7           0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           3,04         0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00         0,00  |  |                        | 0'0                  | 0'0                      | 312,5               |     |    |
| 0         0,0  |  |                        | 0.0                  | 0'0                      | 589,4               |     |    |
| 0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0         0,0         0,0         0,0         0,0           1         0,00         0,0  | Aggressives  |                        | 0'0                  | 0'0                      | 0'0                 |     |    |
| 0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           1         0,00         0,00         0,00           0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00   | Chloride cont. [% of cem.] 0,  | 0,00                   | 0.0                  | 0'0                      | 0'0                 |     |    |
| 0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,00         0,00         0,00           0,00         0,00         0,00         0,00   |  | 0.00                   | 0.0                  | 0.0                      | 0.0                 |     |    |
| 0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,0         0,0         0,0           0,0         0,00         0,00         0,00           0,0         0,00         0,00         0,00           0,00         0,00         0,00         0,00           0,00         0,00         0,00         0,00  | rocks [%]  | 0'0                    | 0'0                  | 0'0                      | 0'0                 |     |    |
| 0,0         0,0           0,0         0,0           0,0         0,0           3,04         0,08           0,00         0,08           0,00         0,08           0,00         0,00           0,00         0,00  |  |                        | 0'0                  | 0'0                      | 0,0                 |     |    |
| 0,0         0,0           0)         0,00         0,00           3,04         0,08         0,08           0,00         0,00         0,00           0,00         0,00         0,00  |  |                        | 0'0                  | 0'0                      | 0'0                 |     |    |
| 3)         0.00         0.00           3.04         0.08         0.08           0.00         0.00         0.00           0.00         0.00         0.00  |  |                        | 0.0                  | 0'0                      | 0,0                 |     |    |
| 3,04 0,08 0,08 0,00 0,00 0,00 0,00 0,00 0  |  |                        | 0'0                  | 0'0                      | 00'0                |     |    |
| 0,00 0,00 0,00   |  |                        | 0'0                  | 0'0                      | 3,04                |     |    |
| 0,00 0,00  |  |                        | 0'0                  | 0'0                      | 0,00                |     |    |
|  |  |                        | 0'0                  | 0'0                      | 00'0                |     |    |
| e 0,0 0,0  |  |                        | 0'0                  | 0'0                      | 0'0                 |     |    |
| 0'0  |  |                        | 0'0                  | 0'0                      | 0,0                 |     |    |
| Prop. concrete density. (kg/m <sup>3</sup> ) 2424  |  |                        | 0                    | •                        |                     |     |    |

#### Autogenous deformation and relative humidity Concrete with Aalborg Portland cement and fly ash

### Mixture 2

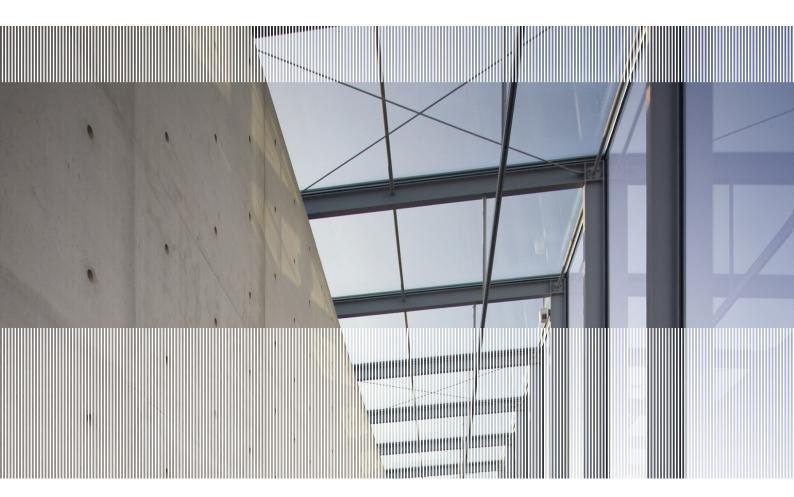
| K         Prepared by<br>000         Company<br>040           0.00 <th>Proportioning of concrete</th> <th>ete</th> <th></th> <th>Project:</th> <th>3D0059.30 Aai</th> <th>3D0059.30 Aalborg Rapid - Mix 2</th> <th></th> <th></th> <th><math>\bigcirc</math></th> <th>SIN</th> <th><b>SINTEF</b></th>  | Proportioning of concrete                    | ete   |        | Project:   | 3D0059.30 Aai     | 3D0059.30 Aalborg Rapid - Mix 2 |                    |                  | $\bigcirc$ | SIN                         | <b>SINTEF</b>        |
|---|--|-------|--------|--|-------------------|---------------------------------|--------------------|------------------|------------|-----------------------------|----------------------|
| State         Kall         Company         Company           Marra [Si)         0.0         200         0.0         200         0.0         0.0           Value         5         0.0         2.00         0.0  | © 2008-11-12 <i>xx</i>                       |       |        |  |                   |                                 |                    |                  |            |                             |                      |
| Mumel (s)         0.40            7 ssh) (s)         0.0         0.00         0.40            7 ssh) (s)         0.0         0.00         0.40             7 ssh) (s)         0.0         0.00         0.00         0.00         0.00         0.00           m SKY552         0.71         0.00   | Initial parametres                           | Value | k      |  |                   | Prepared by                     | Comp               | any              |            | Date                        | Date                 |
| Image: Section of Sectin of Sectin of Section of Section of Section of Section of Secti   | v/(c+Σkp)                                    | 0,40  | •      |  |                   | Lars Haugan                     | SINTE              | F Byggforsk      |            | 2010                        | -06-02               |
| Vision         00         0.40         Material         Materia   |  | 0'0   | 2,00   |  |                   |                                 |                    |                  |            |                             |                      |
| Int [N]         10         -         31000         3100         3100  | f/c (filler, fly ash) [%]                    | 0'0   | 0,40   |  |                   | Material                        |                    |                  |            | onte Alkali                 | Ċ                    |
| Image: Series in the image in the    | Air content [%]                              |       | -      | and the second s | S and In          |                                 |                    | 0                | _          |                             | _                    |
| mr 10 (11:19)         0.00  | Admixtures                                   |       | % av S | A COMPANY  | The car           | Aalborg Rapid                   |                    | 316              |            |                             |                      |
| Im SiX7 552         0.71         0.00         365         1010         365           Inter         000         000         000         1000 <td< td=""><td>BASF Micro Air 110 (1:19)</td><td></td><td>00'0</td><td>A A</td><td>「二」の語言のか</td><td>Silika</td><td></td><td>220</td><td></td><td></td><td></td></td<>   | BASF Micro Air 110 (1:19)                    |       | 00'0   | A A  | 「二」の語言のか          | Silika                          |                    | 220              |            |                             |                      |
| Image: Set Micro Mit 110 (11-9)         000   | BASF Glenium SKY 552                         |       | 0,00   | 10   | の一般の方法            | Aalborg White                   |                    | 316              |            | $\vdash$                    | $\vdash$             |
| 0.00         0.00 <th< td=""><td></td><td></td><td>00'0</td><td>AL DE DE</td><td>「日間の小村</td><td>BASF Micro Air 110 (1</td><td>(19)</td><td>108</td><td></td><td>00'0</td><td>╞</td></th<>   |  |       | 00'0   | AL DE DE   | 「日間の小村            | BASF Micro Air 110 (1           | (19)               | 108              |            | 00'0                        | ╞                    |
| Notify         Notify         Notify         1200           Ibe         0.0         Notify         See If the         1200           Notify         See If the         7800         7800           Notify         Marted         Kee Actives         7800         7800           Set  |  |       | 00'0   | No. of the other   | 「日本にあり            | BASF Glenium SKY 5              | 52                 | 104              |            | -                           |                      |
| Ibre         0.0         Inter         100<   | Fibre  | Vol % |        |  |                   |                                 |                    | 120              |            | 00'0                        | 0,00                 |
| Ibre         0.0         Stell fune         7800           Volume*/ (Im*)         355         Perflice         7800         7800           Volume*/ (Im*)         355         Perflice         For admotinesseriedensy is stated.         7800           Volume*/ (Im*)         355         Matted         Active seried         7800         7800           Volume*/ (Im*)         355         Matted         For admotinesseriedensy is stated.         7800           Wolume*/ (Im*)         355         Matted         Active seried         7800         7800           Wolume*/ (Im*)         355         Matted         Active seriedensy is stated.         7800           Wolume*/ (Im*)         355         Matted         Active seriedensy is stated.         7800           Wolume         Matted         Matted         Matted         Matted         Matted           Matted         Matted         Matted         Matted         Matted <td></td> <td>0'0</td> <td></td> <td>1</td> <td>いいないの</td> <td></td> <td></td> <td>100</td> <td></td> <td>00'0</td> <td>00'0</td>   |  | 0'0   |        | 1  | いいないの             |                                 |                    | 100              |            | 00'0                        | 00'0                 |
| Verdit<br>volume [lm1]         Verdit<br>305         Perifore         Perifore         Tone         1000           Volume**         0.30         For earmin, paccomination (missing), stated for dy make<br>for earmin, paccomination (missing), stated for dy make<br>mit paste (lm1)         302         For earmin, paccomination (missing), stated for dy make<br>for earmin, paccomination (missing), stated for dy make<br>for adminition (missing), stated for dy make<br>for adminit (missing), s | PP-fibre                                     | 0'0   |        | and the second   | - Anna and        | Steel fibre                     |                    | 780              | '<br>0     | '                           | •                    |
| Violume (lmm <sup>1</sup> )         355<br>355<br>355<br>volume*ri (lmm <sup>1</sup> )         Terr remem. percontinue wert dematy is stared for dry marked<br>volume*ri (lmm <sup>1</sup> )         355<br>355<br>355<br>357<br>357<br>357<br>357<br>357<br>357<br>357   | Matrix                                       | Verdi |        | The second se  | A STATE           | PP-fibre                        |                    | 100              | ·<br>0     | '                           | •                    |
| Volume <sup>++</sup> [l/m <sup>-1</sup> ]         355         For admotures wert demisity is stated.           Interstell         302         302           Interstell         302         Set "Achiever" = "Winned": Cell M         Set "Achiever" = "Winned": Cell M           Actinity         302         106         106         Weight Wolf         250           Actinity         423.6         106         106         Weight Wolf         248           Actinity         100         00         00         00         100           102         00         00         00         106         106           112.7         235         23.5         148         148           112.7         0.0         0.0         0.0         0.3365         2448           112.7         0.0         0.0         0.0         0.3365         2448           112.7         112.8         114.8         Means (cg/m <sup>-1</sup> )         2448           112.7         0.0         0.0         0.0         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00  | Wanted matrix volume [I/m <sup>3</sup> ]     | 355   |        |  | and the second    | *For cement, pozzolans og       | fillers density is | s stated for drv | materials. |                             |                      |
| International         302           Accinit         302           Accinit         302           Accinit         302           Accinit         302           Accinit         Set*Achined*T CHIN           Actinitie         Fash concrete           Actinitie         Manted volume         25.0           Actinitie         Noneerty         Presh concrete           Actinitie         Noneerty         Presh concrete           Actinitie         Noneerty         25.0         10.0           Actinitie         Noneerty         Presh concrete         Presh concrete           Actinitie         None         None         Noneerty         Presh concrete           Actinitie         None         None         None         None         None           Actinitie         None         None         None         None         None   | Achieved matrix volume** [l/m <sup>3</sup> ] | 355   |        |  |                   | For admixtureswet density       | y is stated.       |                  |            |                             |                      |
| 0         0.30           *ccIril         Set *Achievel* = "Namber": CHM           *ccIril         Set *Achievel* = "Namber": CHM           *ccIril         Set *Achievel* = "Namber": CHM           *ccIril         Kgim²         Kgim²           433         Kgim²         Kgim²           10,6         0,0         0,0         0,0           11,7         Vanted Achievel* = "Namber": CHM         Fresh concrete           11,7         Kgim²         Kgim²         Fresh concrete           11,7         Vanted Yolume         25,0         Vanted Yolume           11,7         Vanted Yolume         23,5         23,5         23,5           11,7         Vanted Yolume         Mass. con. dens. (kg/m³)         24,48           11,7         Vanted Yolume         23,5         23,5         23,5           11,7         Vanted Yolume         10,0         0,0         0,0   | Volume cement paste [l/m']                   | 302   |        |  |                   |                                 |                    |                  |            |                             |                      |
| Matrix         Set "Achieve" = "Wanted": CHM         Set "Achieve" = "Wanted": CHM           ed concrete         Varied Achieve         Fresh concrete           Agin         Name         Name         Name           167         0.0         0.0         0.0         Name         Name           167         167         10         0.0 <td>M/D</td> <td>0,30</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>  | M/D  | 0,30  |        |  |                   |                                 |                    |                  |            |                             |                      |
| Set "Achinevel" = "Warted": CIAN         Fresh concrete           kg/m³         Varted Achieved         Fresh concrete           kg/m³         Varted Achieved         Fresh concrete           10,0         0,0         0,0         0,0         0,0         10,6         Variated volume         25,0         10,6           11,7         0,0         0,0         0,0         0,0         10,6         Variated volume         25,0         10  | ***Adjust matrix volume; Ctrl M              |       | _      |  |                   |                                 |                    |                  |            |                             |                      |
| Add Concrete         Kap kg         Kg         Kg         Kg         Fresh concrete           433.6         10.6         10.6         10.6         Named volume         25.0           10.0         0.0         0.0         0.0         Named volume         25.0           117.3         0.0         0.0         Named volume         25.0           117.3         4.2         4.2         4.2         10.0           117.7         0.0         0.0         Named volume         10.0           117.7         0.3         0.3         4.2         4.2         4.2           117.7         0.3         0.3         14.2         14.8         14.8           117.7         0.0         0.0         0.0         0.0         0.00   |  |       | _      | Set "Achievel" =   | "Wanted"*, Ctrl N |                                 |                    |                  | ***Rese    | ***Reset correction; Ctrl K | CHK<br>CHK           |
| kg/m³         kg         kg         kg         kg           423,6         10,6         10,6         10,6         Waight volume         25,0           0,0         0,0         0,0         0,0         Waight volume         25,0           0,0         0,0         0,0         0,0         25,0         25,0           0,0         0,0         0,0         Marced volume         25,0           16,7         0,0         0,0         Marced volume         25,0           16,7         0,0         0,0         Marced volume         25,0           16,7         0,0         0,0         0,0         14,8         14,8           12,7         23,5         23,5         23,5         23,6         14,8           13,5         7,8         7,8         7,8         14,8         14,8           0,0         0,0         0,0         0,0         0,00         0,00         0,00           0,0         0,0         0,0         0,0         0,0         0,0         0,0           0,00         0,0         0,0         0,0         0,0         0,0         0,0           0,00         0,00         0,00         0,0  | Proportioned concrete                        |       |        |  | Achieved          | Fresh concrete                  | •                  |                  | Volu       | me cor                      | Volume correction*** |
| 423,6         10,6         10,6         10,6         10,6         25,0           0,0         0,0         0,0         0,0         0,0         25,0         25,0           10,3         0,0         0,0         0,0         0,0         25,0         25,0           15,3         0,3         0,3         0,3         0,3         14,0         25,0           11,7         0,3         0,3         0,3         0,3         14,8         14,9         14,9<  | Materials                                    |       |        | kg   | kg                | Property                        |                    |                  | COLT.      | air corr.c                  | corr.dens corrected  |
| 0,0         0,0         0,0         0,0         0,0         25,0           167,3         0,0         0,0         0,0         1,0         25,0           167,3         1,2,7         0,3         0,3         1,0         24,8           12,7         0,3         0,3         0,3         1,0         0,36           12,7         0,3         0,3         1,4         Macontent (%)         0,36           13,5         23,5         23,5         23,5         23,6         14,8           13,5         7,8         7,8         7,8         7,8         14,8           0,0         0,0         0,0         0,0         0,0         0,36         14,8           0,0         0,0         0,0         0,0         0,0         14,8         14,8           0,0         0,0         0,0         0,0         14,8         14,8         14,8           0,0         0,0         0,0         0,0         14,8         14,8         14,8           0,0         0,0         0,0         0,0         14,8         14,8         14,8           10(119)         0,0         0,0         0,0         14,8         14,8         1   | Aalborg Rapid                                | 423,6 |        | 10,6   | 10,6              | Wanted volume                   | 25,                | 。                | 0'0        |                             | 7                    |
| 0,0         0,0         0,0         0,0         0,0         0,0         1,0           167,3         4,2         4,2         4,2         4,2         4,2         1,0           167,3         3,3         5         24.8         0,35         24.8         1,0           167,3         3,3         2,3         2,3         5         24.8         1,0           13,5         7,8         7,8         7,8         7,8         7,8         7,8         7,8           13,5         7,8   | Silika                                       | 0'0   |        | 0'0  | 0'0               | Weight volume (I)               | 25,                | 。                | 0,0        |                             |                      |
| 167.3         4.2         4.2         4.2         4.2         Meas. con. dens. (rg/m <sup>3</sup> )         248           12.7         0.3         0.3         0.3         0.3         0.3         0.3           313.5         7.8         7.8         7.8         7.8         7.8         7.8         7.8           93.5         7.8         7.8         7.8         7.8         7.8         7.8         7.8           93.5         7.8         7.8         7.8         7.8         7.8         7.8         7.8           93.5         7.8         7.8         7.8         7.8         7.8         7.8         7.8           93.5         7.8         7.8         7.8         7.8         7.8         7.8         7.8           93.0         0.0         0.0         0.0         0.0         0.00         0.  | Aalborg White                                | 0'0   |        | 0'0  | 0'0               | Air content (%)                 |                    |                  | 0'0        |                             |                      |
| 12.7         0.3         0.3         0.3         0.3         0.335           939.5         23.5         23.5         23.5         23.5         0.355           939.5         23.5         23.5         23.5         23.5         0.355           931.5         14.8         14.8         14.8         0.0         0.0         0.05           0         0.0         0.0         0.0         0.0         0.0         0.00         0.00           0.0         0.0         0.0         0.0         0.0         0.0         0.00         0.00           0.0         0.0         0.0         0.0         0.0         0.00         0.00         0.00         0.00           0.0         0.0         0.0         0.0         0.0         0.00  | Free water                                   | 167,3 |        | 4,2  | 4,2               | Meas. con. dens. (kg/           |                    |                  | 0,0        | _                           |                      |
| 939.5         23.0         0.00         0.0   | Absorbed water                               | 12,7  |        | 0,3  | 0,3               | Effective v/(c+Σkp)             | _                  | 5                | 0'0        | _                           | -                    |
| 5         7.8         7.8         7.8         7.8           0         0.0   | Svelvik 0/8                                  | 939,5 |        | 23,5   | 23,5              |                                 |                    |                  | _          | _                           | +                    |
| 691.2         14,8         14,8           0.0         0.0         0,0         0,0           0.10         0,0         0,0         0,0           0.10         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           1.11         0,0         0,0         0,0           0.0         0,0         0,0         0,0           0,0         0,0         0,0         0,0<  | Svelvik 8/16                                 | 313,5 |        | 7,8  | 7,8               |                                 |                    |                  | 9          | +                           | +                    |
| 0         0,0         0,0         0,0         0,0         Aggressives           0,0   | Årdal 16/24                                  | 591,2 |        | 14,8   | 14,8              |                                 |                    |                  | 0.0        | -                           | <u> </u>             |
| 0,0         0,0         0,0         0,0         0,0           1         0,0   | 0  |       |        | 0'0  | 0'0               | Aggressives                     |                    |                  | 9,0        | _                           | _                    |
| 0,0         0,0         0,0         0,0         0,0         0,0           0,0   |  | 0'0   |        | 0'0  | 0'0               | Chloride cont. [% of c          |                    | 。                | 9.0        | +                           | +                    |
| 0.0         0.0         0.0         0.0         0.0           Air 110 (1:19)         0.0         0.0         0.0         0.0         0.0           Air 110 (1:19)         0.00         0.00         0.00         0.00         0.00         0.00           Win SkY 552         3.01         0.00         0.00         0.00         0.00         0.00         0.00           Um SkY 552         3.01         0.00  |  | 0'0   |        | 0'0  | 0'0               | Alkalies [kg/m <sup>3</sup> ]   |                    | 。                | 0,0        | 0;0                         | +                    |
| 0,0         0,0         0,0         0,0           Air 110 (1:19)         0,0         0,0         0,0         0,0           Um SKY 552         3,01         0,00         0,00         0,00         0,00           Um SKY 552         3,01         0,00         0,00         0,00         0,00         0,00           Um SKY 552         3,01         0,00         0,00         0,00         0,00         0,00           Um SKY 552         3,01         0,00  |  | 0'0   |        | 0'0  | 0'0               | Share of react. rocks           | _                  |                  | 0,0        | _                           | _                    |
| 0.0         0.0         0.0         0.0           Air 110 (1:19)         0.00         0.00         0.00           Um SkY 552         3.01         0.00         0.00           Um SkY 552         3.01         0.00         0.00           Um SkY 552         3.01         0.00         0.00           0.0         0.00         0.00         0.00           0.0         0.00         0.00         0.00           0.0         0.00         0.00         0.00           0.0         0.00         0.00         0.00           0.0         0.0         0.00         0.00   |  | 0'0   |        | 0'0  | 0'0               |                                 |                    |                  | 0          | +                           | +                    |
| Air 110 (1:19)         0.0         0.0         0.0           Um SkY 552         3.01         0.00         0.00         0.00           Um SkY 552         3.01         0.00         0.00         0.00           0.00         0.00         0.00         0.00         0.00           0.00         0.00         0.00         0.00         0.00           0.00         0.00         0.00         0.00         0.00           0.0         0.00         0.00         0.00         0.00           0.0         0.0         0.0         0.0         0.0   |  | 0'0   |        | 0'0  | 0'0               |                                 |                    |                  | 0          | _                           | -                    |
| Air 110 (1:19) 0,00 0,00 0,00 um SkY 552 3,01 0,08 0,08 0,08 0,08 0,08 0,08 0,08 0  |  | 0'0   |        | 0'0  | 0'0               |                                 |                    |                  | 0'0        | _                           | _                    |
| um SKY 50.2 3.01 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0   | BASF Micro Air 110 (1:19)                    | 0,00  |        | 0,00   | 0,00              |                                 |                    |                  | 000        | +                           | +                    |
| 0.00         0.00         0.00           0.00         0.00         0.00         0.00           0.0         0.00         0.00         0.00           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0           0.0         0.0         0.0         0.0   | BASE GIENIUM SKY 552                         | 3,01  |        | 0,08   | 0,08              |                                 |                    |                  | 5          | +                           | +                    |
| 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0   |  | 0,00  |        | 0,00   | 0,00              |                                 |                    |                  | 0,0        |                             | 0,00                 |
| 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0   |  | 0,00  |        | 0,00   | 0,00              |                                 |                    |                  | 0          | _                           |                      |
| ete density (ko/m <sup>3</sup> ) 2448   | Steel fibre                                  | 0,0   |        | 0'0  | 0'0               |                                 |                    |                  | 0,0        | 0.0                         | 0,0                  |
| 3448  | PP-II0Ie                                     | n'n   |        | 0'0  | 0,0               |                                 |                    |                  |            | +                           | ╉                    |
|   | Prop. concrete density. (Kg/m*)              | 2448  |        |  |                   |                                 |                    |                  | 0          | 0,0                         | 0 2448               |

## Mixture 3

|  |  |        |        |                       |  |                               |                       | J               |             |               | I         |    |
|--|--|--------|--------|-----------------------|--|-------------------------------|-----------------------|-----------------|-------------|---------------|-----------|----|
| americanic field         oute         km           americanic field         oute         km           (eff-fib)         0.0         0.0         0.0  | @200\$+11-12,rr                              |        |        |                       |  |                               |                       |                 |             |               |           | en |
| victoritarii (s)<br>arronantii | Initial parametres                           | Value  | ×      |                       |  | Prepared by                   | Company               |                 |             | Date          |           |    |
| Image: Section Sectin Section Sectin Section Section Section Section Section Section Se  | v/(c+Σkp)                                    | 0,45   |        |                       |  | Lars Haugan                   | SINTEF By             | ggforsk         |             | 2010-06-02    | 0         |    |
| Image:   | s/c (silica fume) [%]                        | 0'0    | 2,00   |                       |  |                               |                       |                 |             |               |           |    |
| Micronentifie         4 micronenti   | f/c (filler, fly ash) [%]                    | 50,0   | 0,40   |                       |  | Material                      |                       |                 | Dry conte   |               | Chlorides |    |
| Micro Nrt 10 (T1-19)         Yawo K  | Air content [%]                              | 4,0    | '      | A.                    | A MALEN  |                               |                       | 0               | [%]         | [%]           | [%]       |    |
| Micro Mr. 110 (11:9)         000   | Admixtures                                   | % av C | % av S | A COMPANY             | State and  | Aalborg Rapid                 |                       | 3160            | •           | 0,00          | 0,00      |    |
| Glentum SKY 552         200         000  | BASF Micro Air 110 (1:19)                    | 0,00   | 0,00   | No. No.               | 「二」の語言のが   | Silika                        |                       | 2200            | 100         | 0,00          | 0,00      |    |
| 000         000 <td>BASF Glenium SKY 552</td> <td>2,00</td> <td>0,00</td> <td>1</td> <td>の一般がない</td> <td>Flyveaske</td> <td></td> <td>2200</td> <td>100</td> <td>0,00</td> <td>0,00</td> <td></td>   | BASF Glenium SKY 552                         | 2,00   | 0,00   | 1                     | の一般がない   | Flyveaske                     |                       | 2200            | 100         | 0,00          | 0,00      |    |
| 0.00         0.00 <th< td=""><td></td><td>00'0</td><td>0,00</td><td>A STATE</td><td>「日田山子村</td><td>BASF Micro Air 110 (1:</td><td>19)</td><td>1084</td><td>0</td><td>00'0</td><td>0,00</td><td></td></th<>   |  | 00'0   | 0,00   | A STATE               | 「日田山子村   | BASF Micro Air 110 (1:        | 19)                   | 1084            | 0           | 00'0          | 0,00      |    |
| Notice         Notice         1200         0           Perficie         0.0         Perficie         1000         0           Perficie         0.0         Perficie         1000         0           Terrent paste film)         252         Perficiencia         1000         0           diratity volume*/limi)         252         Perficiencia         Forestant         Forest  |  | 00'0   | 0'00   | No.                   | 「日本ところ」  | BASF Glenium SKY 55           | 2                     | 1040            | 17,5        | 0,00          | 0,00      |    |
| Steel fibre         00  | Fibre  | Vol %  |        |                       |  |                               |                       | 1200            | 0           | 0,00          | 0,00      |    |
| PF-fibre         00         Contact Nume         100         1           Inditr volume <sup>11</sup> 325         State flore         7800         -           Inditr volume <sup>11</sup> 325         Perfate         1000         -           Inditr volume <sup>11</sup> 325         Perfate         Terestance defate defat   |  | 0.0    |        | 2                     | いいいないとう  |                               |                       | 1000            | 0           | 00.00         | 0.00      |    |
| Image: Name         Vertion         255         PP-fupe         1000         -           Imatrix volume*" [Im1)         325         Imatrix volume*" [Im1)         325         Imatrix volume*" [Im1)         325           ecenant paste (Im1)         272         Imatrix volume*" [Im1)         275         Imatrix volume*" [Im1)         275           w/b         0,0         0,0         0         Imater volume*" [Im1)         276         Imater volume*" [Im1)         276           w/b         0,0         0,0         0,0         0,0         0,0         0,0         0,0           w/b         125,1         3,1         3,1         Mater volume (a)         25,0         0,0         0,0           waler         125,1         3,3         3,4         Mater volume (a)         25,0         0,0         0,0           waler         125,1         3,3         3,4         Mater volume (a)         26,0         0,0 <t< td=""><td>PP-fibre</td><td>0'0</td><td></td><td>and the second second</td><td>- A State State</td><td>Steel fibre</td><td></td><td>7800</td><td>•</td><td></td><td></td><td></td></t<>   | PP-fibre                                     | 0'0    |        | and the second second | - A State State  | Steel fibre                   |                       | 7800            | •           |               |           |    |
| Imattix volume (limit)         325<br>20         Fer cerrent, paccellerady is stated for dry material.<br>For actinuous stated.           Imattix volume (limit)         325<br>0.05         Imattix volume (limit)         250<br>0.05           wild         0.26           wild         250         0.01           wild         250         0.01           wild         250         0.01           wild         250         0.00           135,1         34         148           wild         148         0.00         0.00           14         148         0.00         0.00           15         7.8         148         0.00           16         0.00         0.00         0.00           16         0.00         0.00         0.00         0.00           <  | Matrix                                       | Verdi  |        | H and                 |  | PP-fibre                      |                       | 1000            |             |               |           |    |
| Imatrix volume <sup>™</sup> [µm]         225         Eventure state of an introvention state of a motivity and a motivity of a motivit   | Wanted matrix volume [l/m <sup>3</sup> ]     | 325    |        |                       | and the second s | *For cement, pozzolansog f    | llers density is stat | ed for dry mate | srials.     |               |           |    |
| e cement paste [mn]         272           w/lo         0.26           w/lo         0.26           rwouker.cm/l         East set set set set set set set set set s  | Achieved matrix volume** [I/m <sup>3</sup> ] | 325    |        |                       | -  | For admixtures wet density    | is stated.            |                 |             |               |           |    |
| w(b)         0.26           intravalume. Crit M.         Terre M. <t< td=""><td>Volume cement paste [I/m<sup>2</sup>]</td><td>272</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>   | Volume cement paste [I/m <sup>2</sup> ]      | 272    |        |                       |  |                               |                       |                 |             |               |           |    |
| Introduction         Introduction<   | Q/M  | 0,26   |        |                       |  |                               |                       |                 |             |               |           |    |
| Title         Farsh Curran         Terman         Te  | ** Adiiist matrix volume: Otd M              |        |        |                       |  |                               |                       |                 |             |               |           |    |
| Interface         Karted         Achieved         Fresh concret         Interface         Interface <thinterface< th=""> <thinterface< th=""> <thi< td=""><td></td><td></td><td></td><td>Set "Achieve" =</td><td>"Wanted"", Ctrl N</td><td></td><td></td><td></td><td>***Dacation</td><td>action. Otd K</td><td></td><td></td></thi<></thinterface<></thinterface<>  |  |        |        | Set "Achieve" =       | "Wanted"", Ctrl N  |                               |                       |                 | ***Dacation | action. Otd K |           |    |
| Valued Acrilevol         Fresh concrete           i         kg/m³         kg         kg         resh concrete         volume           i         kg/m³         kg         kg         kg         resh concrete         resh concrete           i </td <td></td> <td></td> <td></td> <td></td> <td></td> <td>L</td> <td></td> <td></td> <td>Inclusion 1</td> <td></td> <td></td> <td></td>   |  |        |        |                       |  | L                             |                       |                 | Inclusion 1 |               |           |    |
| apid         kgm/         kg         kgm/         corrain           2pid         250,1         6,3         6,3         6,3         0 <td< th=""><th>Proportioned concrete</th><th></th><th></th><th>wanted</th><th>Achieved</th><th>Fresh concrete</th><th></th><th>-</th><th>Volume</th><th>correct</th><th></th><th></th></td<>  | Proportioned concrete                        |        |        | wanted                | Achieved   | Fresh concrete                |                       | -               | Volume      | correct       |           |    |
| dapid         250,1         6,3         6,3         6,3         6,3         6,3         6,3         0,0  | Materials                                    | kg/m°  |        | kg                    | kg   | Property                      |                       |                 |             | corr.dens o   | corrected |    |
| 0.0         0.0 <td>Aalborg Rapid</td> <td>250,1</td> <td></td> <td>6,3</td> <td>6,3</td> <td>Wanted volume</td> <td>25,0</td> <td></td> <td>0,0</td> <td>0'0</td> <td>250,1</td> <td></td>  | Aalborg Rapid                                | 250,1  |        | 6,3                   | 6,3  | Wanted volume                 | 25,0                  |                 | 0,0         | 0'0           | 250,1     |    |
| ε         125,1         3,1         3,1         3,1         3,1         4,0         0,0 <td>Silika</td> <td>0'0</td> <td></td> <td>0'0</td> <td>0'0</td> <td>Weight volume (I)</td> <td>25,0</td> <td></td> <td>0'0</td> <td>0'0</td> <td>0'0</td> <td></td>   | Silika                                       | 0'0    |        | 0'0                   | 0'0  | Weight volume (I)             | 25,0                  |                 | 0'0         | 0'0           | 0'0       |    |
| rt         135,1         3,4         3,4         3,4         3,4         0,0 <td>Flyveaske</td> <td>125,1</td> <td></td> <td>3,1</td> <td>3,1</td> <td>Air content (%)</td> <td>4,0</td> <td></td> <td>0'0</td> <td>0'0</td> <td>125,1</td> <td></td>  | Flyveaske                                    | 125,1  |        | 3,1                   | 3,1  | Air content (%)               | 4,0                   |                 | 0'0         | 0'0           | 125,1     |    |
| Water         12,7         0,3         0,3         0,3         0,3         0,0<  | Free water                                   | 135,1  |        | 3,4                   | 3,4  | Meas. con. dens. (kg/n        |                       |                 | 0'0         | 0'0           | 135,1     |    |
| 8 (93) (10 (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)   | Absorbed water                               | 12,7   |        | 0,3                   | 0,3  | Effective v/(c+Σkp)           | 0,450                 |                 | 0'0         | 0'0           | 12,7      |    |
| 16         313.5         7,8         7,8         7,8         7,8         7,8         7,9         0,0 <td>Svelvik 0/8</td> <td>939,5</td> <td></td> <td>23,5</td> <td>23,5</td> <td></td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>939,5</td> <td></td>  | Svelvik 0/8                                  | 939,5  |        | 23,5                  | 23,5   |                               |                       |                 | 0'0         | 0'0           | 939,5     |    |
| 24       591.2       14,8       14,8       0,0 <t< td=""><td>Svelvik 8/16</td><td>313,5</td><td></td><td>7,8</td><td>7,8</td><td></td><td></td><td></td><td>0'0</td><td>0'0</td><td>313,5</td><td></td></t<>   | Svelvik 8/16                                 | 313,5  |        | 7,8                   | 7,8  |                               |                       |                 | 0'0         | 0'0           | 313,5     |    |
| 0         0,0  | Årdal 16/24                                  | 591,2  |        | 14,8                  | 14,8   |                               |                       |                 | 0'0         | 0'0           | 591,2     |    |
| 0,0         0,0 <td>0</td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>Aggressives</td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>0'0</td> <td></td>   | 0  |        |        | 0'0                   | 0'0  | Aggressives                   |                       |                 | 0'0         | 0'0           | 0'0       |    |
| 0,0         0,0 <td></td> <td>0'0</td> <td></td> <td>0'0</td> <td>0'0</td> <td>Chloride cont. [% of ce</td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>0'0</td> <td></td>   |  | 0'0    |        | 0'0                   | 0'0  | Chloride cont. [% of ce       |                       |                 | 0'0         | 0'0           | 0'0       |    |
| 0,0         0,0 <td></td> <td>0'0</td> <td></td> <td>0'0</td> <td>0'0</td> <td>Alkalies [kg/m<sup>3</sup>]</td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>0,0</td> <td></td>   |  | 0'0    |        | 0'0                   | 0'0  | Alkalies [kg/m <sup>3</sup> ] |                       |                 | 0'0         | 0'0           | 0,0       |    |
| 0,0         0,0 <td></td> <td>0'0</td> <td></td> <td>0'0</td> <td>0'0</td> <td>Share of react. rocks [9</td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>0'0</td> <td></td>  |  | 0'0    |        | 0'0                   | 0'0  | Share of react. rocks [9      |                       |                 | 0'0         | 0'0           | 0'0       |    |
| 0,0         0,0 <td></td> <td>0'0</td> <td></td> <td>0'0</td> <td>0'0</td> <td></td> <td></td> <td></td> <td>0'0</td> <td>0'0</td> <td>0,0</td> <td></td>  |  | 0'0    |        | 0'0                   | 0'0  |                               |                       |                 | 0'0         | 0'0           | 0,0       |    |
| To Air 110 (1:19)         0,0  |  | 0'0    |        | 0'0                   | 0'0  |                               |                       |                 | 0'0         | 0'0           | 0,0       |    |
| Tro Air 110 (1:19)         0.00         0.00         0.00         0.0  |  | 0'0    |        | 0,0                   | 0'0  |                               |                       |                 | 0'0         | 0'0           | 0,0       |    |
| nium SKY 552 5,00 0,13 0,13 0,13 0,13 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,   | BASF Micro Air 110 (1:19)                    | 0,00   |        | 0,00                  | 0,00   |                               |                       |                 | 0,0         | 0'0           | 0,00      |    |
| 0.00         0.00         0.00         0.00         0.0  | BASF Glenium SKY 552                         | 5,00   |        | 0,13                  | 0,13   |                               |                       |                 | 0'0         | 0'0           | 5,00      |    |
| 0,00         0,00         0,00         0,0<  |  | 0,00   |        | 0,00                  | 0,00   |                               |                       |                 | 0'0         | 0'0           | 0,00      |    |
| e 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,   |  | 0,00   |        | 0,00                  | 0,00   |                               |                       |                 | 0,0         | 0'0           | 0,00      |    |
| 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0  | Steel fibre                                  | 0.0    |        | 0'0                   | 0'0  |                               |                       |                 | 0,0         | 0'0           | 0.0       |    |
| 0.0 0.0 0.0  | PP-fibre                                     | 0'0    |        | 0'0                   | 0'0  |                               |                       |                 | 0'0         | 0'0           | 0,0       |    |
|  | Prop. concrete density. (ka/m <sup>3</sup> ) | 0300   |        |                       |  |                               |                       |                 | 0           | 0             | 0000      |    |

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