Elise Marie Rong Anfinsen
Aleksandra Marie Høye
Margrethe Munch-Ellingsen

Effect of Calcium Nitrate as Accelerator for Cement Blended with Blastfurnace Slag

Effekten av kalsiumnitrat som akselerator for sement blandet med masovnslagg

Bachelor thesis in Civil Engineering
Supervisor: Arne Mathias Selberg
External supervisor: Mehrdad Torabzadegan
May 2022

Norwegian University of Science and Technology
Faculty of Engineering
Department of Structural Engineering

NTNU

ABSTRACT

Curing in cold climate can be a challenging matter, as extreme cold temperatures will halt the hydration and therefore also the curing process.

There is already a few well-developed methods to protect concrete from severe temperatures. However, the most commonly used methods are costly and time consuming as they rely on manual labor, by covering the structure in cold protective formwork. Alternative methods are needed.

An option is to utilize admixtures to optimize the curing processes. One alternative admixture is NitCal. NitCal was developed by Yara, and is a mixture of purified nitrate salts.

The main goal of this thesis is to investigate the effect of NitCal as a setting accelerator in cement blended with blastfurnace slag, cured in a cold climate.

To fulfill the above goal, the following tests were conducted: compressive strength test, isothermal calorimetry test, thermogravimetric analysis, as well as measuring the core temperature of concrete cubes during curing.

In the design mix, cement has been replaced with 50% ground, granulated blastfurnace slag (GGBS). Initially three design mixes were created, all with different concentrations of CN, 0%, 2% and 4%. Compressive strength tests was performed after 1, 2, 7 and 28 days. Detailed information is given in **Appendix C**.

The results indicated a high early strength for the samples containing NitCal. This was a trend in both the compressive strength test results and the cumulative heat development of the isothermal calorimetry test results.

Keywords: Accelerator, blastfurnace slag, calcium nitrate, calorimetry, cement, strength, thermogravimetric, hydration.

SAMMENDRAG

Herding i kaldt klima kan være en krevende prosess, da ekstrem kulde vil forsinke hydratasjonen og dermed også herdeprosessen.

Det finnes allerede etablerte metoder for vinterstøp. Disse metodene er kostbare og tidskrevende, da de innebærer omfattende arbeid ved å tildekke konstruksjoner med store kuldebeskyttende komponenter. Det er høy etterspørsel for alternative og mer brukervennlige metoder.

En alternativ metode er å benytte seg av størkningsakselererende tilsettningsstoffer. Et slikt størkningsakselerende tilsetningstoff er blandt annet NitCal. NitCal er utviklet av Yara, og er en blanding av rensende nitratsalter.

Hovedmålet med denne bacheloroppgaven er å undersøke effekten av kalsiumnitrat som akselerator for sement blandet med masovnslagg, herdet i kaldt klima.

For å oppnå dette målet er følgene tester gjennomført: trykkfasthetstester, isoterm kalorimetri-test, termogravimetrisk analyse, samt måling av kjernetemperatur til betongterninger under herding.

I resepten har sement blitt byttet ut med 50% masovnslagg (GGBS). I utgangspunktet ble det laget tre resepter, der alle hadde ulik konsentrasjon av CN, 0%, 2% og 4%. Trykkfasthetstester ble utført etter dag 1, 2, 7 og 28. Mer detaljer om dette finnes i **Appendix C**. Resultatene indikerer en høy tidlig styrke for betongterningene som inneholder NitCal. Dette er en trend som viser seg både i trykkfasthetstesten og i den kumulative varmeutviklingen fra isoterm kalorimetri.

Nøkkelord: Akselerator, masovnslagg, kalsiumnitrat, kalorimetri, sement, styrke, termogravimetri, hydratasjon.

PREFACE

This bachelor thesis is written by Elise Marie Rong Anfinsen, Aleksandra Marie Høye and Margrethe Munch-Ellingsen and serves as a submission to the course BYGT2900, spring of 2023 at the Institute of Structural Engineering at the Norwegian University of Science and Technology. The bachelor thesis is compiled as independent work with the guidance of Professor Arne Mathias Selberg.

When choosing a subject for our thesis, we approached Yara as we wanted to cooperate with a company serving great knowledge and resources within concrete technology. This was to ensure the optimization of our progress, understanding and knowledge throughout the different stages of our research. Yara has provided great guidance and support through our external supervisors Mehrdad Torabzadegan and Ninjo Neuhaus. We hope our results will be useful for continuous work and research on the topic.

Trondheim 22.05.2023

Elise Marie Rong Anfinsen | Aleksandra Marie Høye | Margrethe Munch-Ellingsen

ACKNOWLEDGMENTS

We would like to show our appreciation to Arne Mathias Selberg, Kåre Olsby, Thomas Uhlving and the rest of the staff at NTNU's laboratory for structural engineering. Their contributions concering practicalities in the laboratory, as well as their share of knowledge on concrete has been well appreciated.

We would also like to extend our gratitude to Mehrdad Torabzadegan, Ninjo Neuhaus and the rest of Yara, for giving us the opportunity to immerse ourselves in the subject by composing this thesis. A special thank you to Mehrdad Torabzadegan, serving as our external supervisor for his encouragement, flexibility and share of great knowledge throughout this process.

Lastly, we would like to extend our sincerest gratefulness to Harald Justnes from SINTEF for his guidance, time and support throughout this work. His contributions regarding share of knowledge, encouragement and valuable comments has led to a steep learning curve on our behalf.

CONTENTS

ABBREVIATIONS

- **BX** Batch 1-9
- **CN** Calcium Nitrate
- **CN 2 - 50** Sample containing 2% NitCal in a mixture of 50% v 50% GGBS v CEM
- **CN 4 - 50** Sample containing 4% NitCal in a mixture of 50% v 50% GGBS v CEM
- **C-S-H** Calsium silicate hydrate
- **GGBS** Ground granulated blast-furnace slag
- **ITC** Isothermal Titration Talorimetry
- **ITZ** Interfacial transition zone
- **Lab** Laboratory
- **NitCal** Calcium Nitrate
- **NTNU** Norwegian University of Science and Technology
- **OPC** Ordinary Portland Cement
- **PSD** Particle size distribution
- **REF - 1** Reference sample containing 0% CN
- **SINTEF** The Foundation for Industrial and Technical Research
- **SCM** Supplementary cementing materials
- **SP** Super Plasticizer
- **TGA** Thermogravimetric Analyzer
- **TS** Tensile strength
- **UTS** Ultimate tensile strength
- **w/b** Water/binder

- **w/c** Water/cement
- **K‘** The permeability coefficient
- **SD** Standard Deviation

CHAPTER

ONE

INTRODUCTION

1.1 Backround

Curing in cold climate can be a challenging matter. Freezing of pore water in a curing construction will halt the hydration, and therefore also the curing process.

There are already a few well-developed methods to protect concrete from extreme low temperatures. The most commonly used methods are:

- **Isolating materials**
  Concrete throws off heat during the chemical reactions of curing. To retain the heat, insulating blankets and insulated framework can be used. This process takes a great amount of work, effort and supervision. It is important to secure the insulation for wind, and to prevent overheating of the concrete, which can trigger thermal stress.

- **Heated enclosures**
  Strong weather-proof heated enclosures work as an external heating effect. Additional water may be needed to prevent the concrete surface from drying.

Both methods however, are costly and time consuming, and alternative methods are much needed. [33]

This thesis will examine the use of NitCal as a concrete setting accelerator, which can be used as an alternative in cold climate environments. NitCal was developed by Yara, and is a mixture of purified nitrate salts.
There are several advantages to NitCal [29]:

- NitCal uses hydration heat to prevent freezing, and thereby does not shift the freezing point of water.
- Due to plasticizers, NitCal neutralizes the retardation of concrete setting.
- Combined with a superplasticizer, NitCal optimizes the consumption of water and cement.
- NitCal reduces corrosion of the reinforcement in concrete.

1.2 Reasearch Goal

The main goal of this research is to investigate the effect of calsium nitrate as an accelerator in cement blended with blastfurnaced slag, cured in a cold climate.
To fulfill the above goal, the following tests were conducted:

- Compressive strength test
- Isothermal calorimetry
- Thermogravemetric analysis
- Measuring core temperature during curing

3 sets of concrete samples has been moulded, all with different concentrations of CN. Two parallels of cement paste for each concentration has been set. The results have been compared.
The idea is that Yara can make use of this data to further develop their product, NitCal.

From a student perspective, a subgoal has been to gain knowledge of concrete technology, to further our understanding of concrete strength, and to be introduced to laboratory activity.

1.3 Constraints

C The scope of work changed multiple times due to several constraints. The changes listed below resulted in a new scope of work, **Appendix C**.

- **Number of samples**
  The original proposal of scope of work, **Appendix C**, suggested a comprehensive collection of samples, 72 casts to be exact. The proposal were strongly advised against by internal supervisors and lab technicians since this would equal the workload of a larger scale. The scope of work was then reduced to moulding 24 samples. See **Appendix C**
- **Change of test day 3**
  In the original scope of work compressive strength were to be tested on day 3. However due to lab capacity, casting of samples found place on a Wednesday, and therefore test day 3 would have occured on a Saturday. After seeking advice from one of the internal supervisors it was decided to test compressive strength on day 2 instead of day 3.
- **Flexural strength**
  Testing of flexural strength was removed from the scope of work, due to lab capacity and report requirements. The lab time was restricted by several factors.

  – The students needed to be supervised by employees/lab technicians at NTNU, which led to restrictions due to their schedule.

- The lab was also rapidly used by other students, and professors. This created restrictive time slots for moulding the samples.

CHAPTER

TWO

THEORY

This chapter will review the theory behind the materials and tools, the concept of curing, permeability and hydration, and the importance of compressive strength in concrete. All aspects has been used when researching the effect of NitCal as an setting accelerator.

2.1 Components/Materials

The properties of the concrete depends on the combination of materials chosen in the concrete matrix. The design is mainly determined by requirements to compressive strength and durability, set by NS - EN 206. However, it is equally important that properties such as workability are satisfactory and in accordance to the production.

Achieving a perfect mix can be a delicate matter, and the basis for this has mainly been a material model called *the particle-matrix model*, PMM. PMM describes the realtionship between mix-design and workability for both standard structural concrete, as well as self-compacting concrete. [38]

This section will review the theory behind the components used in Set 1, Set 2.1 and Set 2.2.

2.1.1 Binder

2.1.1.1 Cement

Cement is a chemical substance used for construction that sets, hardens, and adheres to other materials to bind them together. The four major phases of Cements; Tricalcium silicate (Alite), Diacalcium silicate (Belite), Tricalcium silicate (Aluminate) and Tetracalcium aluminoferrite (Ferrite), forms an exothermic reaction with water, implying that heat is generated. [40] The main reaction product is calcium silicate hydrate (C-S-H) which is mainly responsible for the high mechanical strength and impermeability of hardened concrete. [38] [18]

- **CEM I** is pure (100%) OPC (Ordinary Portland Cement) and is compatible with fly ash and blast furnace slag. [28]

- **CEM II** is a mixture where up to 35% of the clinker is replaced by additives. **Table 2.1.1** specifies the composition of the CEM II used in the first set of mix design. [27]

A-V Portland Fly ash cement		
Materials	Value	Unit
Clinker	74,7	%
Gypsum	6,3	%
Fly ash	15,1	%
Limestone filler	3,9	%

Table 2.1.1: Product specification of the CEM II used in the mix design. [11]

2.1.1.2 Ground Granulated Blast-furnace Slag

GGBS is a by-product from the blast-furnaces used to make iron. [39] [5] The cementitious material, whose main use is in concrete, hardens very slowly on its own. For use in concrete it needs to be activated by combining it with cement or alkali hydroxides.

A typical concrete composition can consist of 50% GGBS and 50% Portland cement. However, percentages of GGBS can vary anywhere between 20% and 80 %. GGBS have a finer pore size distribution than that of Portland cement concrete.

The increase of GGBS has a parallel effect on the concrete properties. Slag concrete have an increased resistance against chloride penetration and increases the resistance against sulphate attack and alkali silica reaction. [31]

2.1.2 Pozzolans

A pozzolan is a siliceous and aluminous material that can impart some very favorable properties on concrete. Pozzolans can be divided into the groups active addition and non-active additions.

Active addition implies chemical reactivity either alone or in combination with Portland cement clinker and/or its hydration products.

Non-active additions are used extensively as fillers. As an additive to cement, it reacts with calcium hydroxide, $Ca(OH)_2$, and contributes to increased density and strength in concrete [19]. The most common additives in Norway are silica fume and fly ash. Pozzolans are included in the mass ratio:

$$m = w/(c + k * p) \tag{2.1}$$

where k is an efficiency factor for the actual property and the actual material. [38] [12]

2.1.2.1 Silica Fume

Silica fume is a by-product from the ferrosilicon and silicon metal industry used to enhance mechanical and durability properties of concrete. [38] The microscopic sized particles, varying from 0.1 to 0.2 μm, contribute to high density and good resistance in concrete. [7]
In the fresh state of concrete, silica fume will lead to a low slump value and high plastic shrinkage. To achieve the same workability as of conventional concrete, silica fume concrete requires a higher water content.
In a hardened state, silica fume affects the concrete by giving high early compressive strength and long durability. [12] [13]

2.1.3 Aggregates

Aggregates usually occupy 65% to 75% of the concrete's volume. The allocation of aggregates plays a huge role in the concrete's properties. The grading of aggregates, also called the PSD curve or siege curve of aggregates, influences the materials properties.

Changes in the finest part of the sand siege curve ($<$ 1 mm) can lead to significant variations in workability and water demand for concrete. Changes in the material grading may influence the concrete's air content. [38] A higher sand content contributes to a higher content of filler materials, and therefore an increased flow resistance. This will also increase the concrete's stability. [2]

2.1.3.1 Årdal 0/8

The PSD curve for Årdal 0/8 follows a typical sieve curve for 0/8 mm Norwegian Natural Sand, with a "sand hump". See **Figure 2.1.1**

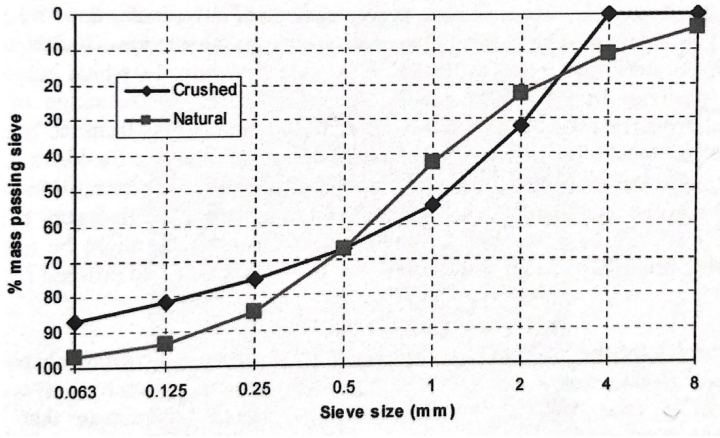


Figure 2.1.1: Typical sieve curve for 0/8 mm sand [38]

2.1.3.2 Årdal 8/16 mm

The PSD curve for Årdal 8/16 follows a typical sieve curve for 0/16 mm. See **Figure 2.1.2**. For Årdal 8/16 the last half of the curve is relevant.

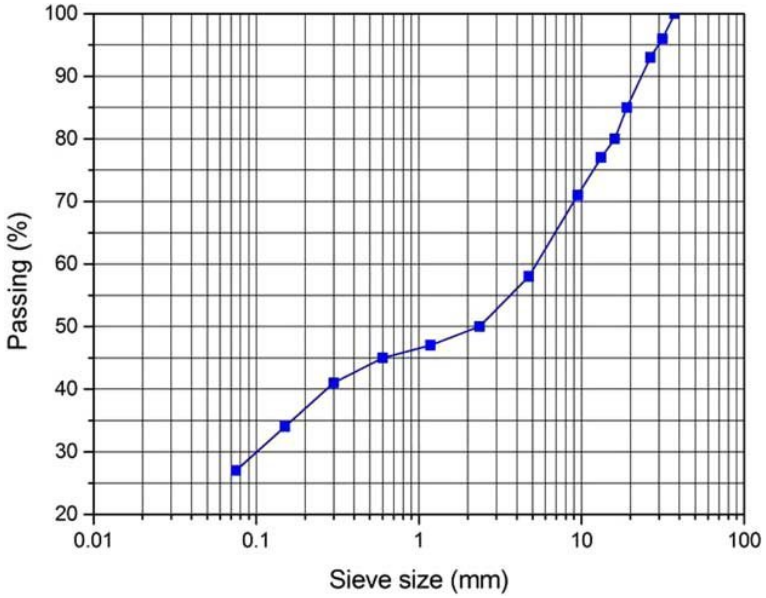


Figure 2.1.2: General Sieve Curve [43]

2.1.4 Water

The amount of water in the matrix is set by the w/b ratio. **Figure 2.1.3** displays the connection between w/b and flow resistance, where an increase in w/b results in a decrease of flow resistance [38]. An increase of water decreases both viscosity of plastic flow and yield shear stress [2]. An overview of limits and durability classes for different w/b ratios can be found in NS - EN 206 [38].

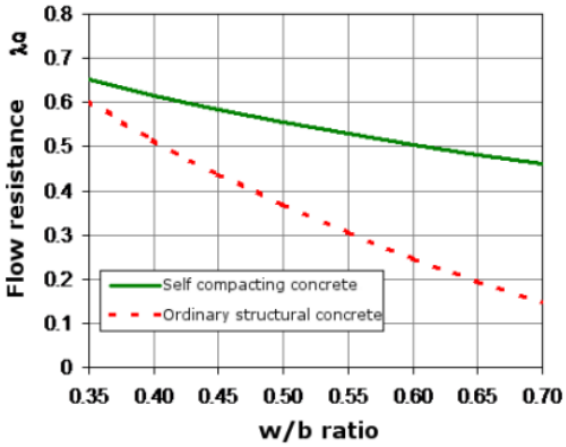


Figure 2.1.3: Flow resistance of matrix as a function of w/b [2]

2.1.5 Chemical Admixtures

Chemical admixtures are ingredients added during the mixing process of concrete. There are several different chemical admixtures depending on the favorable modification.
Some of the beneficial effects chemical admixtures can add to concrete is:

- Frost resistance
- Sulfate
- Controlled setting and hardening
- Improved workability
- Increased strength

[34] [38] [8]

2.1.5.1 NitCal

NitCal concrete setting accelerator (CN), developed by Yara, is a mixture of purified nitrate salts. CN is an established concrete admixture used for accelerating the cement hydration, especially in extremely low temperatures. CN has been a common setting accelerator for many years in line with EN 934-2 table 6 or ASTM C494 type C. [29] The effect and its performance have been evaluated in the early 90s by Justnes and Nygaard (1993) [17].
CN increases soluble calcium content in the freshly mixed concrete. The calcium concentration causes earlier formation and precipitation of calcium hydroxide and accelerate formation of calcium silicate hydrate (C-S-H) by reducing initial crystallization time and eventually renewal of alite hydration. However, in blended cements CN does not react directly with SCMs but indirectly by reacting with the calcium aluminate hydrate compounds formed. [29]

2.1.5.2 Superplasticizer

Mapei Dynamon SX-23 is an effective SP additive made of modified acrylic polymers. It is developed to be used in all concrete types to make the concrete easier to process and/or reduce the need for water. The SP disperses the flocculated cement particles effectively in the water. This substantially increases the workability and fluidity of the concrete, without affecting the strength. [38] [26]

2.1.6 Air

The concrete was of the type non-air entrained, which refers to concrete with no added air-entrained admixtures or air-entrained cement in the mix design. Air-entrained concrete can decrease the strength of the concrete and even though this method can have several advantages, it is more beneficial to use non-air entrained concrete. Non-air entrained concrete usually contains between 1% and 2% entrapped air. [9]
The reason why some projects need air-entrained admixtures is because the concrete is to be placed in areas where it freezes. This research will be conducted in temperatures above freezing, so the advantages of using air-entrained concrete is not relevant. [6]

2.2 Proportioning

The properties of concrete is determined by the selection of raw materials and their distribution. The design is determined by requirements to compressive strength and durability. Other factors affecting the design of concrete is to ensure suitable workability and casting techniques. [38]

2.2.1 The Particle Matrix Model

PMM is an attempt to create a simplified model of the relations between concrete components influencing workability. The model was developed by Ernst Mørtsell at NTNU in 1996. Instead of looking at 7-8 different constituents, which a concrete mixture may contain, the model divides the material into two groups dependent on their properties; the matrix phase and the particle phase.

The matrix phase consists of all fluids and particles 0.125 mm. The definition acknowledges that smaller particles will be controlled by surface properties of the of the material, not the size or shape.

The particle phase consists of the remaining part of the concrete > 0.125 mm, which are in general the aggregate particles. The effect of these particles on concrete flow is mainly governed by density, shape and size distribution. [38]

2.3 Mixing

When mixing from the same mix-design one would expect the same results every time, however in reality the properties will vary somewhat. These variations may be caused by:

- Particle size distribution of sand and aggregate
- Cement properties variations
- Variations of moisture content in aggregates
- Human error when scaling and mixing constituents
- Inconstant time of edition of fluids
- Variations in mixing temperature

If the standard deviation of the compressive strength exceeds 6-7 MPa, the mixture is viewed as out of control and alternations is necessary. [38]

2.3.1 Mix design

Concrete mix design is the science of choosing and proportioning materials to achieve desired strength. [41] The effective water/binder (w/b) ratio is important for the flow properties of concrete, and determines compressive strength and durability. The matrix composition controls the properties in the hardened state. The cement paste has, in most cases, lower durability and strength than the aggregate.

Required compressive strength and durability of the concrete controls the matrix composition, and can be found in NS - EN 206 - 1. [38]

To proportion a concrete is to choose constituents and their relative proportions so that: [40]

- the fresh concrete obtains the desired workability
- the hardened concrete achieves the required properties
- the risk of random defects is acceptable
- the cost level is acceptable

2.3.2 Mixing Procedure

The batches were mixed in *PMat Zyklos 50L Concrete tumbler*. To reduce large variations between batches, a mixing procedure was followed. This is the standard mixing procedure at NTNU and is based on the concept of PMM. The mixing procedure followed the steps given in **Table 2.3.1**.

Mixing Procedure		
Step	Minutes	Mixing
i	1	Dry mixture
ii	2	Wet mixture - add gradually the first 30 sek
iii	2	Set to rest - make adjustments if necessary
iv	1	Mix all together

Table 2.3.1: Mixing procedure at the concrete lab, NTNU

2.4 Curing Technology

There is a considerable amount of heat that develops when cement is hydrated. In most concrete structures this will lead to a temperature increase during the first days after casting. The high temperature will result in a fast hydration process and therefore also a fast strength development.
Low temperatures on the other hand will give a slow hydration process. To avoid a slow strength development, action is required to ensure a correct progress of the concrete curing. [38]

2.4.1 Heat Development

The reaction between cement and water is an exothermic process. The cement is typically composed of different minerals where the various clinker minerals will develop heat differently, and affect each others hydration processes .

The cement will practically never hydrate completely, and the degree of hydration depends mainly on the clinker composition, the fineness of the cement, and the w/b ratio. The moisture conditions and temperature also plays a role.

The degree of hydration depends on how much water the hydration process has available. When the cement hydrates, each grain of cement is encapsulated of hydration products, C-S-H. The further hydration is therefore dependent on the water diffusivity of the C-S-H-layer. The finer the cement is, the higher degree of hydration can be achieved. [38]

2.4.2 The Progress of Hydration

The rate of hydration increases as temperature rises. **Figure 2.4.1** shows heat development in cement as a function of temperature, with a w/b ratio of 0.4 [38].

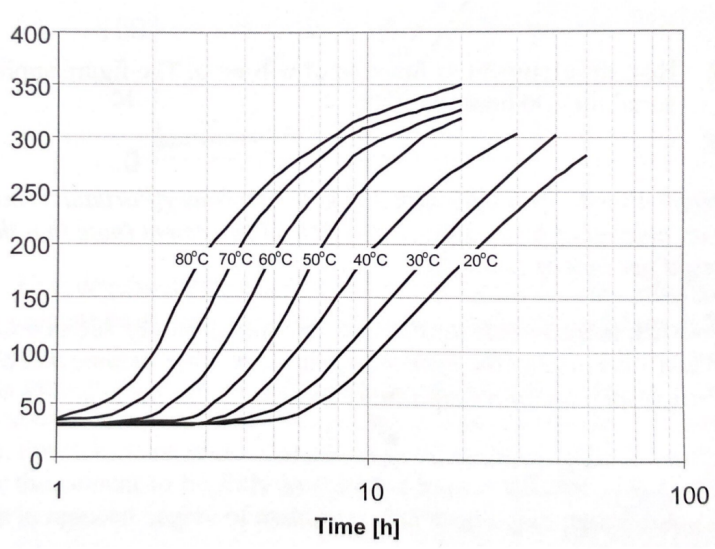


Figure 2.4.1: Heat development as a function of temperature. w/b =0.4

The Arrenhenius equation, H(θ), describes the relation between temperature

and chemical activity of a thermally activated process. The equation is given by:

$$H(\theta) = e^{\frac{E(\theta)}{R}(\frac{1}{293}-\frac{1}{273+\theta})} \tag{2.2}$$

H(θ) gives the rate of hydration at a given temperature, compared with the rate at 20 °C. **Table 2.4.1** shows typical values for the rate function *H(θ)*. For this report the value of 5 °C, highlighted in yellow, is relevant.

Temp.	H(θ)	Temp.	H(θ)
0	0.15	20	1.00
1	0.17	21	1.05
2	0.20	22	1.10
3	0.23	23	1.15
4	0.26	24	1.20
5	0.29	25	1.26
6	0.33	26	1.32
7	0.37	27	1.38
8	0.41	28	1.44
9	0.45	29	1.51
10	0.50	30	1.57
11	0.54	31	1.64
12	0.59	32	1.72
13	0.64	33	1.79
14	0.70	34	1.87
15	0.75	35	1.95
16	0.80	36	2.04
17	0.85	37	2.13
18	0.90	38	2.22
19	0.95	39	2.31
20	1.00	40	2.41

Table 2.4.1: H(θ) values [38]

2.4.3 Development of Concrete Properties

There is mainly two properties taken into consideration when addressing development of properties; strength and heat.
Strength development follows the empirical function below:

$$f_c(M) = f_{c^\infty} * e^{-(\frac{\tau_e}{M})^\alpha} \tag{2.3}$$

The strength development during curing depends only on the maturity, M, the virtual age of concrete. The concretes maturity is calculated through the rate function *H(θ)* (2.4.2). **Figure 2.4.2** shows strength development as a function of time, while **Figure 2.4.3** shows strength development as a function of maturity [38].

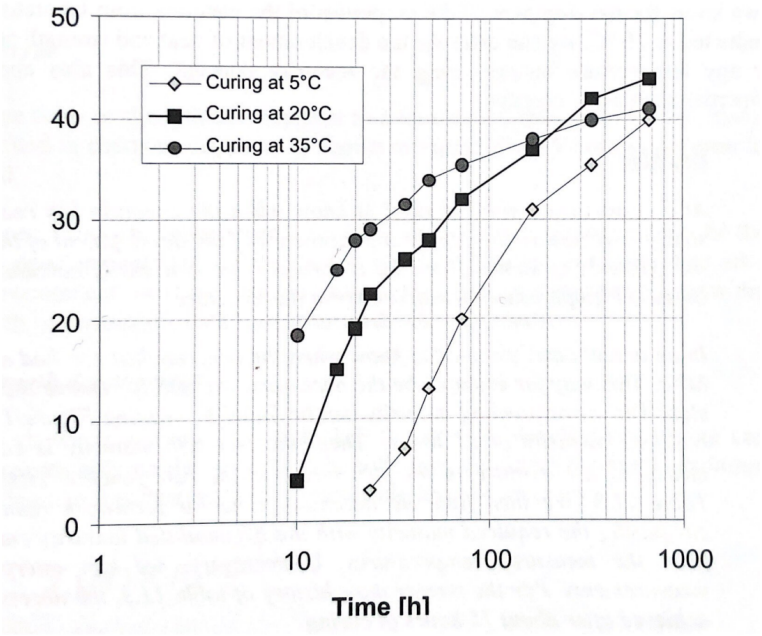


Figure 2.4.2: Compressive Strength as a Function of Time [38]

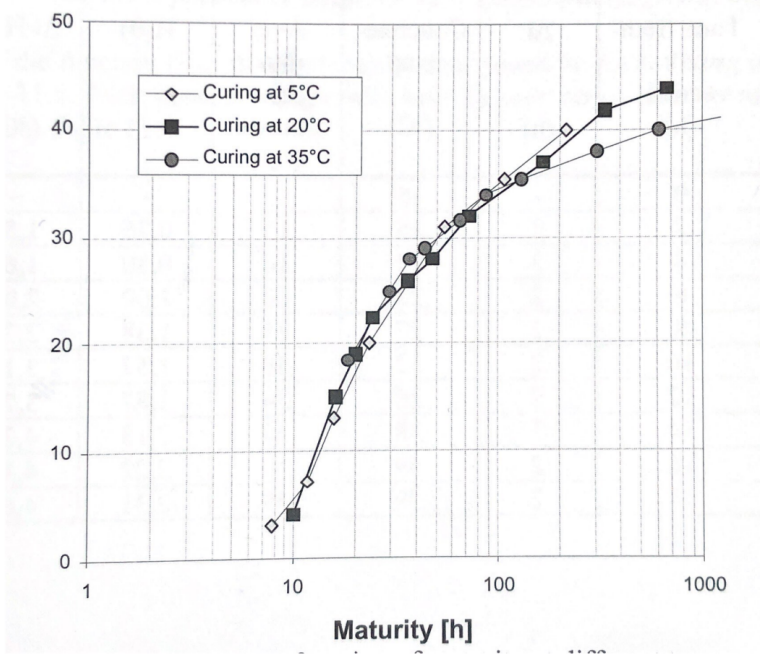


Figure 2.4.3: Compressive Strength as a Function of Maturity [38]

Heat development can be described with the same type of empirical function:

$$Q(M) = Q_\infty e^{-(\frac{\tau_e}{M})^\alpha} \tag{2.4}$$

2.4.4 Curing in Cold Climate

Curing in cold climate is a challenging matter as low ambient temperatures causes large heat loss from the hardening concrete. A large heat loss can result in slow strength development as the cement does not hydrate as fast. The worst case scenario is having the concrete freeze. This entails a temporary stop in the curing process and an irreversible damage in structure, as freeze breaks up the matrix. According to NS 3465 concrete must have a compressive strength of at least 5MPa to be able to withstand freezing during hardening. [38] [33]

To prevent large heat loss and to ensure a steady strength development, it is beneficial to take measures. Two of the most commonly used protective measures are insulated blankets and heated enclosures. Both measures are performed externally on the hardening concrete and can be a time consuming and a costly matter.

Adding accelerating admixtures to the concrete mixture can help offset slow strength gain. Accelerators can be divided into four classes:

- **Calcium chloride** produces an accelerated rate of hydration in cement.
- **Accelerating admixtures** contains enough calcium chloride, water reducers, to accelerate setting.
- **Nonchloride accelerating admixtures** increases the rate of hydration of tricalcium silicate (C_3S) and tricalcium aluminate (C_3A) phases of cement. [30]
- **Nonchloride accelerating admixtures also providing freeze protection** can reduce or eliminate the use of other protective measures such as insulated blankets and heated enclosures. [35]

2.5 Compressive Strength

Compressive strength has traditionally been the most important quality of concrete because it is the property that is mainly being utilized in structures [38]. Testing of compressive strength are usually performed on cubes moulded from the concrete batch. [3] [23] Requirements for normal concrete for compressive strength after 28 day are given by NS - EN 206. See **Figure 2.5.1**.

Fasthetsklasse NS	B10	B20	B25	B30	B35	B45	B55	B65	B75	B85	B95
CEN designation		C20/25	C25/30	C30/37	C35/45	C45/55	C55/67				
Characterstic cylinder strength f_{ck}	10	20	25	30	35	45	55	65	75	85	95
Characterstic cube strength $f_{ck\ cube}$ 1)	12	25	30	37	45	55	67	80	90	100	110

Figure 2.5.1: Requirements for Compressive Strength (normal concrete) from NS - EN 206-1, Table NA. 2 [38]

2.6 Permability

Permeability is a measure of water, gases, and other substances that can enter the concrete matrix [4]. The mass transport takes place through the concrete's pore system. [38]

2.6.1 Pore Structure

Cement-based materials contains air-void structures such as gel-pores and capillary pores. The types of pores differs in size, where gel pores are < 10 nm and capillary pores are 10 nm - 104 nm.

Pore structure influences the cement-based material properties; strength and permeability, as well as the environmental stability of engineering materials such as durability and reliability. [25]

2.6.1.1 Cement Paste

Figure 2.6.1 shows the permeability coefficient, K', for stationary water transport in hardened cement paste at different w/c ratios [38].
The graph below shows two things:

1. Improved hydration causes a reduction of porosity and continuity in the pore system, which leads to a reduction of K'.

2. A w/c ratio larger than 0.5 increases K' distinctly.

The classic shape of the curve has led to an international agreement that for "watertight" concrete it is required a w/b-ratio below 0.5. [38]

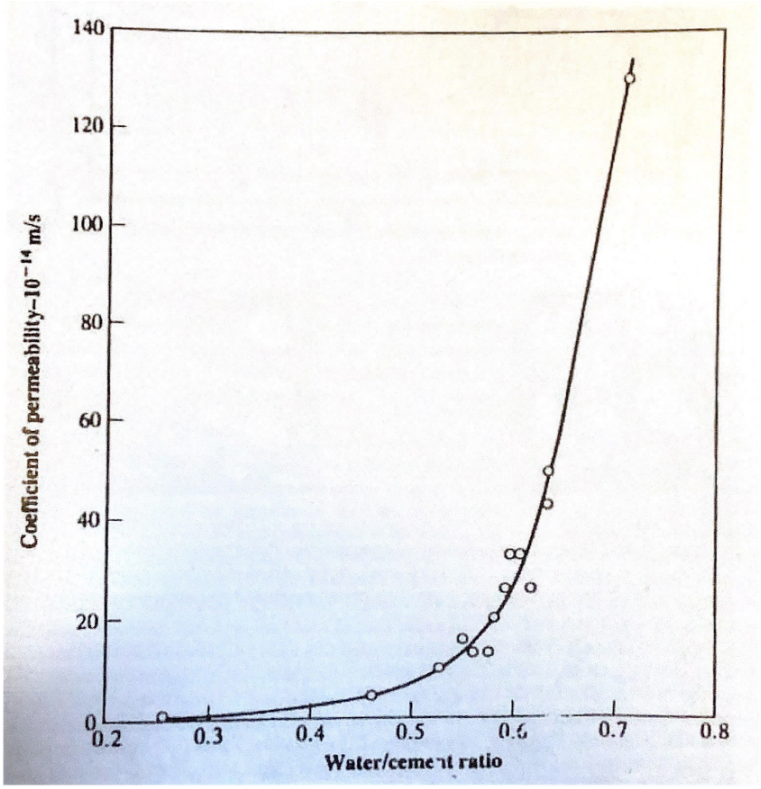


Figure 2.6.1: Relation between permeability and w/c ratio [38]

Figure 2.6.2 shows the reduction of permeability in cement with the progress of hydration, as a function of hardening time. W/c - ratio is set to 0.7.

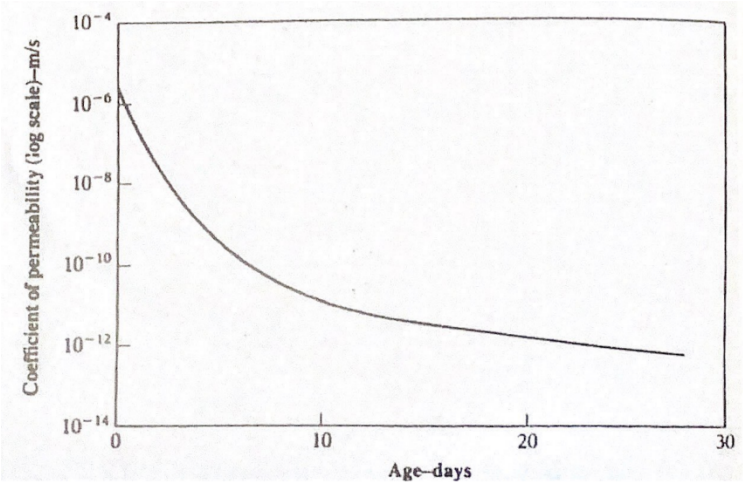


Figure 2.6.2: Relation between permeability and hardening time [38]

2.6.1.2 Concrete

As **Figure 2.6.3** shows that concrete has a higher permeability than its own cement paste, even though aggregates uphold 70% of the volume.

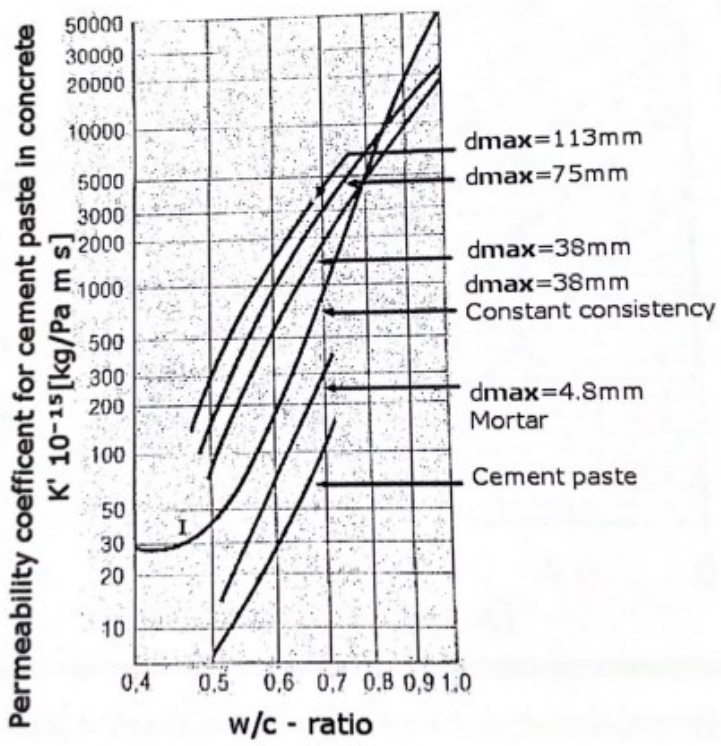


Figure 2.6.3: Permeability coefficient for cement paste in concrete [38]

The explanation can be found in the ITZ, between aggregates and paste. This zone has the width of 10's m and has a higher porosity than the paste, mainly due to reduced packing of the fine cement grains towards larger surfaces such as aggregates and reinforcement. [38]

CHAPTER

THREE

MATERIALS AND EXPERIMENTAL PROCEDURES

Laboratory work entails not only the actual manual labour, it also includes a comprehensive amount of preparations. This chapter will review how to proportion concrete mix designs, preparing samples, method of mixing and quality testing, and lastly how to conduct the different tests analysed in this research.

3.1 Selection of Materials

The cement in Set 1 was of the type CEM II, and the cement in Set 2 was of the type CEM I, according to NS-EN 197-1. Both produced by Norcem, Brevik, Norway. The granulated, ground blastfurnace slags (**Appendix B**) were delivered by Yara through SINTEF. The calcium nitrate (**Appendix B**) was in the form of 50% solution without any foreign ions and is a product of Yara, Porsgrunn, Norway. The Silica Fume in Set I was of the type Elkem microsilica 920, according to NS-EN 206 and produced by Elkem, Thamshavn, Norway. The gravel was of the type Årdal 8/16 mm and the sand was of the type Årdal 0/8 mm nat. vask. Both produced by Heidelberg materials, Årdal, Norway. The superplasticizer was of the type Dynamon SX-23 and produced by Mapei, Sagstua, Norway.

The water used in the hydration test was de-ionized water. The cement used in the hydration test was of type CEM I.

3.1.1 *Proporsjonering* by Sverre Smeplass

In this report an already existing proportioning tool *Proporsjonering* was used to calculate the mix design, **Appendix A** The tool was developed by Sverre Smeplass and allows the user to determine proportions in the mix design, based on material selection and matrix volume. *Proporsjonering* is based on the concept of PMM and allows matrix and aggregate composition to be determined separately. [2]

Table 3.1.1 shows an example of how the matrix composition in a mix design is calculated using the proportioning tool. Under the tab *Matriks* the following properties are determined:

- the mass ratio

- assumed air content
- sub-materials in the matrix phase
- matrix volume in mix design

Initialparametre	Verdi
m = v/(c+Σkp)	0,48
Luftinnhold	2,0 %

Sementtype	Andel	Andel klinker	Andel FA	Andel slagg	[kg/m^3]	Alkalier	Klorider
Norcem Standard FA	0,0 %	82,0 %	18,0 %	0,0 %	2950	1,4 %	0,1 %
Norcem Anlegg	50,0 %	100,0 %	0,0 %	0,0 %	3160	0,6 %	0,1 %
	0,0 %	100,0 %	0,0 %	0,0 %	1000	0,0 %	0,0 %

Tilsetningsmaterialer	Type	Andel (av b)	k	[kg/m^3]	Alkalier	Klorider
Elkem Microsilica	Silika	4,0 %	1,0	2200	0,1 %	0,1 %
Normineral flyveaske	FA	0,0 %	0,7	2200	1,0 %	0,3 %
GGBS	Slagg	50,0 %	0,6	2700	1,0 %	0,3 %

Tilsetningsstoff	% av b	[kg/m^3]	Tørrstoff	[kg/m^3] TS	Alkalier	Klorider
Mapei Dynamon SX-23	1,0 %	1050	23,0 %	1261	0,0 %	0,0 %
Nitcal	2,0 %	1050	50,0 %	1105	0,0 %	0,0 %
	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %
	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %

Fiber	Vol %	[kg/m3]
	0,0 %	7800
	0,0 %	1050

Matriks	Verdi
Ønsket matriksvolum [l/m^3]	320
Oppnådd matriksvolum [l/m^3]	320
Klinkerandel i bindemiddel	23,0 %
Total FA- andel av bindemiddel	0,0 %
Total slaggandel av bindemiddel	50,0 %
Volum sementlim [l/m^3]	279,5
Effektivt vanninnhold [l/m^3]	136,4
v/p	0,28
Effektivt bindemiddel [kg/m^3]	284
Totalt bindemiddel [kg/m^3]	384

Beregn

Figure 3.1.1: Illustration of matrix composition under the "Matriks" tab in *Proposjonering*

The filler proportion in the aggregate composition is determined under the tab "Sammensatt tilslag", as shown in **Table 3.1.2** The weight for each fraction is determined in the column Weight - proportion.

Fraksjon	Navn	Densitet [kg/m^3]	Abs. fukt [%]	Alk. reakt. Sv[%]	Klorider [%]	Andel volum	Andel vekt	Bruk
I	Årdal 0/8 mm nat. vask	2650	0,3	0,0	0,00	0,654	0,650	ok
II	Årdal 0/2 mm nat. vask	2650	0,5	0,0	0,00	0,000	0,000	
III	Årdal 8/16mm	2700	0,4	0,0	0,00	0,346	0,350	ok
IV	Årdal 16/22 mm	2700	0,5	0,0	0,00	0,000	0,000	
V		2700	0,0	0,0	0,00	0,000	0,000	
VI		2700	0,0	0,0	0,00	0,000	0,000	
VII		2700	0,0	0,0	0,00	0,000	0,000	
VIII		2700	0,0	0,0	0,00	0,000	0,000	
IX		2700	0,0	0,0	0,00	0,000	0,000	
X		2700	0,0	0,0	0,00	0,000	0,000	
Sammensatt		2667		0,0	0,00	1,000	1,000	

Figure 3.1.2: Illustration of calculation of aggregates composition under the tab "Sammensatt Tilslag" in the tool *Proporsjonering*

When the matrix composition, aggregate composition and matrix volume is determined, the proportioning tool can calculate the mix design by clicking the "calculate"-button in the matrix tab. The final mix design can be found under the tab "Proposjonert betong", as shown in **Table 3.1.3**. The mix design is given in kg/m^3. A desired size of batch can be determined in this tab.

Proporsjonert betong

Materialer	kg/m^3
Norcem Standard FA	0,0
Norcem Anlegg	114,7
	0,0
Elkem Microsilica	19,9
Normineral flyveaske	0,0
GGBS	249,2
Fritt vann	136,4
Absorbert vann	6,3
Årdal 0/8 mm nat. vask.	1215,0
Årdal 0/2 mm nat. vask	0,0
Årdal 8/16mm	653,6
Årdal 16/22 mm	0,0
	0,0
	0,0
	0,0
	0,0
	0,0
	0,0
Mapei Dynamon SX-23	4,98
Nitcal	9,97
	0,00
	0,00
	0,0
	0,0
Prop. betongdens. (kg/m^3)	2401

Figure 3.1.3: Illustration of calculated mix design in the tool *Proporsjonering*

The amount of each component (kg) is calculated under the tab "Blandeskjema". The calculation is based on the mix design, wanted volume and water content and absorption.

Materialer	Resept kg/m^3	Sats kg	Fukt* %	Korr. kg	Oppveid** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	114,7	1,720			1,720	
	0,0	0,000			0,000	
Elkem Microsilica	19,9	0,299	0,0	0,000	0,299	
Normineral flyveaske	0,0	0,000			0,000	
GGBS	249,2	3,739			3,739	
Fritt vann	136,4	2,046		-0,132	1,913	2,007
Absorbert vann	6,3	0,094			0,094	
Årdal 0/8 mm nat. vask.	1215,0	18,224	0,0	0,000	18,224	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	653,6	9,803	0,0	0,000	9,803	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	5,0	0,075	77	0,058	0,075	
Nitcal	10,0	0,150	50	0,075	0,150	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

Figure 3.1.4: Illustration of mixing scheme under the tab "Blandeskjema" in the tool *Proporsjonering*

The user determines the matrix volume according to wanted consistency, as this is not taken into consideration by the calculation sheet. The amount of superplasticizer was adjusted to each individual mixture to achieve suitable workability and to increase the density. [2]

3.1.2 Hydration Mixture

The composition of hydration mixtures follows SINTEF's standard testing procedures. **Table 3.1.1** shows the materials and its proportioning.

The mixture was utilized in both the isothermal calorimetry test, and the thermogravimetric analysis.

Hydration Mix Design		
Sample	Material	Amount
Ref - 1	CEM I	13g
	GGBS	13g
	Destilled Water	13g
	CN 2	0g
	CN 4	0g
CN 2 - 50	CEM I	13g
	GGBS	13g
	Destilled Water	0g
	CN 2	13g
	CN 4	0g
CN 4 - 50	CEM I	13g
	GGBS	13g
	Destilled Water	0g
	CN 2	0g
	CN 4	13g

Table 3.1.1: Materials for Hydration Mixture

3.2 Specimen Preparation

As shown in **Table 3.2.1**, nine mix designs were prepared. 100x100x100mm cubes were made for each batch in each set. Compressive strength was measured after 1, 2, 7 and 28 days. An extra cube in Set 1 was prepared and used to measure core temperature using the software program CatMan AP 5.5.2. Core temperature was not measured for Set 2.1 or Set 2.2.

Design Number	Cement	Silica Fume	GGBS	CN 50% solution	Årdal 0-8 mm	Årdal 8-16 mm	Water	Absorbed water	Mapei Dynamon SX-23
1	116,5	20,3	253,5	0,00	1215	653,6	138,6	6,3	5,1
2	114,7	19,9	249,2	10,00	1215	653,6	136,4	6,3	5
3	112,8	19,6	245,3	19,60	1215	653,6	134,2	6,3	4,9
4	177,1	0	177,1	0,00	1100,2	762,9	159,4	6,4	7,1
5	173,1	0	173,1	13,90	1100,2	762,9	155,8	6,4	6,9
6	169,4	0	169,4	27,10	1100,2	762,9	152,4	6,4	6,8
7	175,2	0	175,2	0,00	1247,1	622,9	157,7	6,2	3,5
8	171,2	0	171,2	13,70	1253,5	616,8	154,1	6,2	3,4
9	167,5	0	167,5	26,80	1253,5	616,8	150,7	6,2	3,3

Figure 3.2.1: Mix design, stated in kg/m^3

Three mix designs were proportioned for Set 1, **Table 3.2.2**. These mix designs followed NTNU's standard procedure for proportioning. However, the mix designs

in Set 1 contained Silica Fume and did not follow a cement and gravel ratio of 50% v 50%.

Design Number	Cement	Silica Fume	GGBS	CN 50% solution	Årdal 0-8 mm	Årdal 8-16 mm	Water	Absorbed water	Mapei Dynamon SX-23
1	116,5	20,3	253,5	0,00	1215	653,6	138,6	6,3	5,1
2	114,7	19,9	249,2	10,00	1215	653,6	136,4	6,3	5
3	112,8	19,6	245,3	19,60	1215	653,6	134,2	6,3	4,9

Figure 3.2.2: Mix design for Set 1, stated in kg/m^3

Three mix designs were proportioned for Set 2.1, **Table 3.2.3**. However, only one mix design was prepared as the trial mix indicated a separated concrete sample.

Design Number	Cement	Silica Fume	GGBS	CN 50% solution	Årdal 0-8 mm	Årdal 8-16 mm	Water	Absorbed water	Mapei Dynamon SX-23
4	177,1	0	177,1	0,00	1100,2	762,9	159,4	6,4	7,1
5	173,1	0	173,1	13,90	1100,2	762,9	155,8	6,4	6,9
6	169,4	0	169,4	27,10	1100,2	762,9	152,4	6,4	6,8

Figure 3.2.3: Mix design for Set 2.1, stated in kg/m^3

The mix design was adjusted by changing the ratio between gravel and sand from 30% v 70% to 1:2. The proportions of MAPEI SX-23, SP, was reduced to achieve the wanted texture. In the adjusted mix design of Set 2.2, illustrated in **Table 3.2.4**, eight 100x100x100mm cubes were made for each batch.

Design Number	Cement	Silica Fume	GGBS	CN 50% solution	Årdal 0-8 mm	Årdal 8-16 mm	Water	Absorbed water	Mapei Dynamon SX-23
7	175,2	0	175,2	0,00	1247,1	622,9	157,7	6,2	3,5
8	171,2	0	171,2	13,70	1253,5	616,8	154,1	6,2	3,4
9	167,5	0	167,5	26,80	1253,5	616,8	150,7	6,2	3,3

Figure 3.2.4: Mix design for Set 2., stated in kg/m^3

The moulding of samples were conducted in the order shown in **Table 3.2.1**.

The mix was blended in accordance to **Table 2.3.1** using PMat Zykols 50L Concrete tumbler. To achieve suitable workability and to increase the density, the SP was adjusted to each individual mixture.

Casting was performed using the technique placing layer by layer of concrete. In between each layer the test is temped 25 times and hammered, to vibrate and to avoid air bubbles. One layer is approximately of size 3.3 cm.
The samples were cured in a water bath set at 5 °C.
Demoulding took place consecutively on the specific test day.

Figure 3.2.5: PMat Zyklos 50L Concrete tumbler

Figure 3.2.6: Water bath

3.3 Quality Testing

Quality tests were performed as a part of quality control. To assure the quality of the concrete used in this research, measurements of slump, air-void, temperature, and weight was controlled. These quality tests give an idea about the properties workability, air content, permeability, and density.

3.3.1 Temperature

It is typically required that fresh concrete maintain a temperature between 5 - 32 °C. If the temperature varies outside of this scale, solutions on how to adjust the temperature must be set in action. [42]

The temperature of this reports mix was measured by an infrared thermometer directly after the mix procedure was complete.

Figure 3.3.1: Infrared thermometer used for measuring temperature

3.3.2 Slump Test

A concrete slump test measures the consistency of a batch to see how well the concrete will flow. The concrete's "slump" indicates whether the concretes w/b ratio is too high or low, and if the mix will have a functioning workability [24] [36].

3.3.2.1 Method of Slump test

A slump test was completed by following the steps below (also, see **Table 3.3.2**):

1. A cone shaped container is filled with concrete in three layers, each layer is temped 25 times.

2. The top surface is then struck off by means of screening and rolling motions.

3. The cone is carefully lifted vertically for 8 seconds.

4. The slump is measured by placing the cone besides the slump concrete, and the temping rod is balanced on top of the cone so that it hoovers over the area of the slump.

5. The decrease in height is measured to the nearest mm.

Figure 3.3.2: Method of Slump Test [24]

The results are then categorized into four different categories, depending on the shape of the "slump" [24]

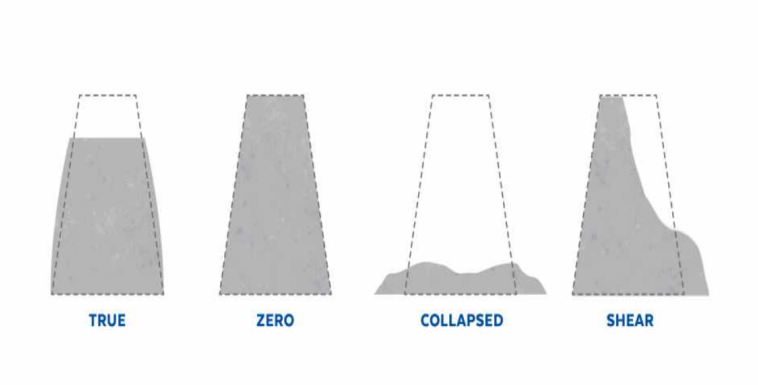


Figure 3.3.3: Slump Test Results [24]

3.3.3 Weight

The unit weight of concrete is defined as the ratio of concrete mass per unit volume. A normal unit weight of concrete weighs approximately 2400 kg per cubic meter [37].
The weight of the fresh concrete was measured on a standard scale.

Figure 3.3.4: Measuring weight of fresh concrete in a 7983cm^2 container

3.3.4 Air Content

In general, air content in concrete is measured to scale the concrete's frost resistance. Tests have shown that concrete with air content above 3-4% has a higher frost resistance compared to concrete with lower air contents [38].
A lower air content can also reduce the fresh concrete's slump.

3.3.4.1 Method of Testing Air Content

The concrete's air content was measured by following the steps below [10]:

1. A container is filled with concrete in three layers, each layer is temped 25 times.

2. To measure the air content, an air-content test device is latched on top of the container. The air gap between the top of the concrete and the underside of the air meter is then filled with water.

3. The test device is pressurized with a built in hand pump until it is zeroed out.

4. After stabilization, the pressure is released, and the air-void content is read on the top of the air meter.

5. The top layer of the sample is dried with a piece of paper, and then mixed back in with the rest of the batch.

Figure 3.3.5: Measuring Air Content

3.4 Material Tests

Numerous tests were conducted on the prepared concrete cubes and hardened cement to obtain the required data. The outline of the tests are presented below, in **Table 3.4.1**:

Material Tests Conducted	
Test	Goal
Compressive Strength	To obtain the capacity of axially forces that different CN concentrated concrete cubes can withstand
Isothermal Calorimetry	To obtain the heat development of different CN concentrated cement pastes
Thermogravimetric Analysis	Measuring weightloss as a function of temperature
Core Temperature	To obtain data of the core temperature of different CN concentrated concrete cubes

Table 3.4.1: Material Tests Conducted

3.4.1 Compressive Strength

To determine concrete quality it is necessary to meassure compressive strength.

For each of the 100x100x100mm cubes a compressive strength test was performed to meassure the compressive strength, according to NS - EN 12390-3. Compressive strength was measured on day 1, 2, 7 and 28, according to **Appendix C**.

Figure 3.4.1 demonstrates the test set up where each cube was placed in the center of the platen of *Toni TROL II, Model 0560*. A weigth plate gradually

added weight and pressure until the reach of breaking point. The results showing the maximum amount of compressive load the material can hold, were graphically presented and saved in the testing software *Test Xpert II – v3.41*.

Figure 3.4.1: *Toni TROL II, Model 0560* performing compressive strength test

3.4.2 Core Temperature

When measuring the concrete's core temperature the following equipment was utilized:

- Software: *CatMan AP 5.5.2*
- A computer
- Wires for measuring temperature

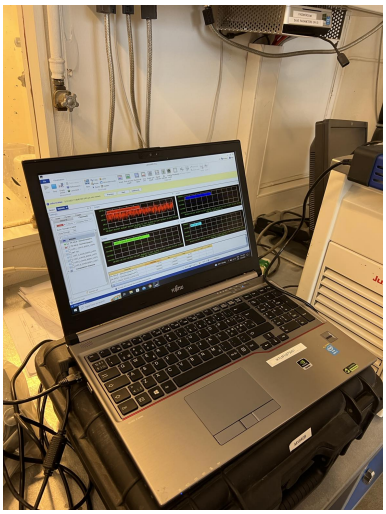


Figure 3.4.2: *CatMan AP 5.5.2*

On the day of moulding, while concrete still was fresh, a thermo-wire was carefully placed in one of the cubes in each batch. All with a different concentration of CN.

The moulds were then placed in a water bath to cure, and the wire was connected to the computer containing the software *CatMan AP 5.5.2* which were to save all the data.
However, *CatMan AP 5.5.2* experienced a software error which caused the data not to be saved. Therefor, this report will not include a core temperature discussion and analysis.

3.4.3 Hydration

The testing of hydration was partly conducted by the students, and partly by SINTEFs scientists.

The mixtures presented in **Table 3.1.1** were set aside for 1 and 28 day(s) for curing. On the day of testing the following steps were conducted:

1. Break the glass vial containing the specimen, and mortar the hardened cement into dust with a mortar.

2. Fill an empty plastic bottle with the dust and pour a generous amount of isopropyl alcohol into the container.

3. Let the dust settle in the isopropyl. Remove the top layer of isopropyl after the dust has settled at the bottom of the flask.

4. Set the flask aside.

The rest of the procedure was conducted by SINTEF.

3.4.3.1 Isothermal Calorimetry

Isothermal calorimetry is a method for measuring binding between any two molecules that release or absorb heat upon binding. [15]

Figure 3.4.3 illustrates the test conducted, where a sample cell containing the protein of interest, and a reference cell containing water, was injected by an injection syringe. After the injection, the heat being released was measured until the binding reaction had reached equilibrium. [32]

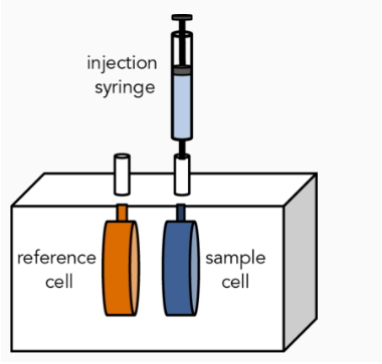


Figure 3.4.3: Illustration of Isothermal Titration Calorimetry [15]

3.4.3.2 Thermogravimetric Analysis

This procedure was conducted by SINTEF and results were delivered for discussion and analysis. The analytical technique is performed by measuring the mass of a sample against time or temperature while the samples temperature is programmed in a controlled atmosphere [14]. The results provide information about both physical and chemical phenomenas. The test is commonly used for determining the composition of samples and predicting their thermal stability [22] [21] [20].

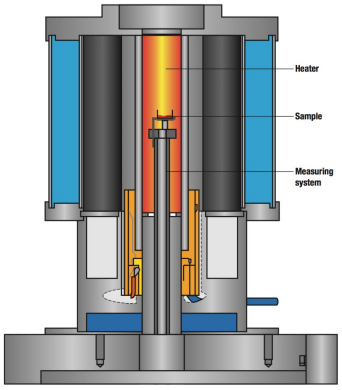


Figure 3.4.4: Illustration of the diagram for a typical Thermogravimetric Analysis system [14]

CHAPTER

FOUR

RESULTS AND ANALYSIS

This chapter presents the results obtained from the test conducted in **Table 3.4.1**. The results are presented both graphically and in tables.

4.1 Quality Testing

The quality tests conducted were measuring of temperature, slump, weight, and air void.

4.1.1 Temperature

Temperature Results of Quality Testing		
Set	Batch	Value
1	Ref - 1 CN 2 -50 CN 4 - 50	21.4°C 20.2°C 19.6°C
2	Ref - 1 CN 2 -50 CN 4 - 50	22.4°C 20.8°C 23.2°C

Table 4.1.1: Temperature results

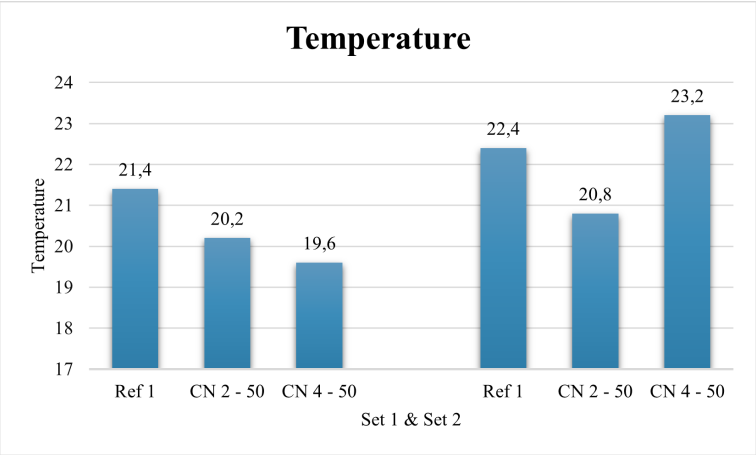


Figure 4.1.1: Temperature, Set 1

The temperature of the batches follows the room temperature.
The temperature in Set 1, **Appendix A.1**, decreases slightly as the concentration of CN increases.
However, there is no immediate connection between temperature in Set 2.2, **Appendix A7**. The lack of connection in Set 2.2 might be explained by the date of casting, CN 4 - 50 was set on another date than Ref - 1 and CN 2 - 50 and so the room temperature may have differed.
There is no science of today that explains the cause of a potential connection between the trend in temperature and concentration to CN. The decrease in fresh concrete temperature might be caused by other external factors.

4.1.2 Slump test

Slump Test Results		
Set	Batch	Value
1	Ref - 1 CN 2 -50 CN 4 - 50	230 mm 230 mm 225 mm
2	Ref - 1 CN 2 -50 CN 4 - 50	220 mm 180 mm 220 mm

Table 4.1.2: Slump Test Results

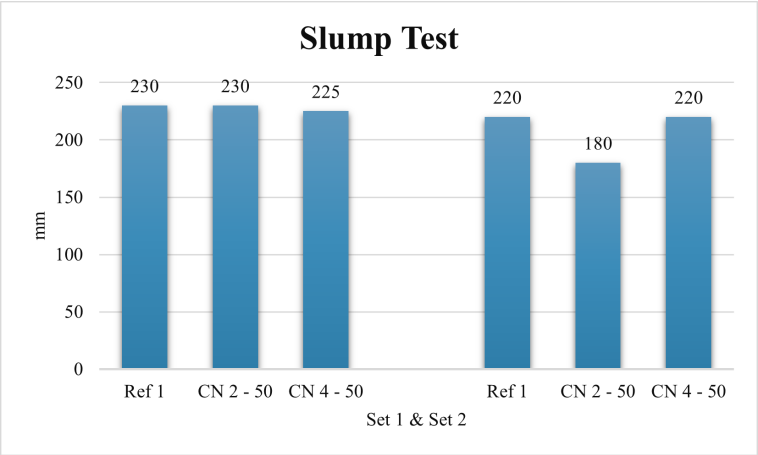


Figure 4.1.2: Slump Test, Set 2

The slump test results for Set 1, **Appendix A.1**, and Set 2.2, **Appendix A.7** ,indicates a good and steady flow mix.
W/b ratio OK. All batches show true slump. See **Figure 3.3.3**.

The concrete held its cone-like shape before it fell into a puddle. This is positive when casting concrete.
Batch 8, CN 2 - 50 in Set 2, had a lower slump than Ref 1 and CN 4 - 50 in the same set. A lower air void content can cause a lower slump, and B8 had a significantly lower air void value than the rest, see **Table 4.1.4**.
The first trial mixing of Set 2.1, **Appendix A**, indicated a separated sample. Which resulted in a change of mix design, see paragraph **5.2.2 Set 2.1 - Separated Sample**.

4.1.3 Weight

Weight Results		
Set	Batch	Value
1	Ref - 1 CN 2 -50 CN 4 - 50	19 486.8 g 19 356.8 g 19 378.8 g
2	Ref - 1 CN 2 -50 CN 4 - 50	19 192.8 g 19 403.8 g 19 313.8 g

Table 4.1.3: Weight results

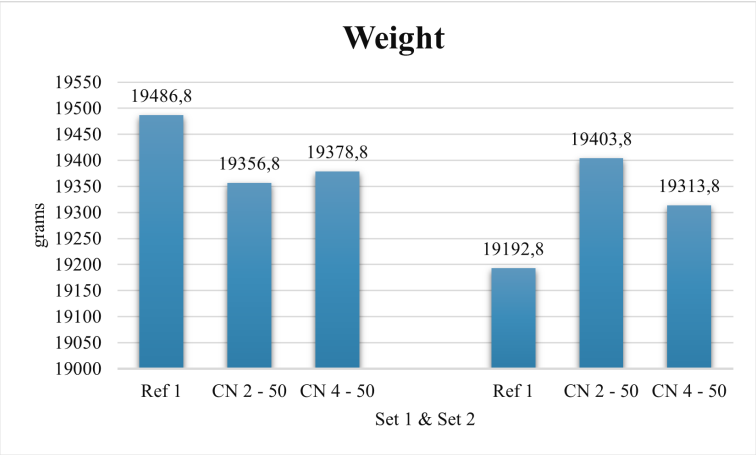


Figure 4.1.3: Weight, Set 1

The weight of the concrete-mix is stable, and show little to no difference with or without CN.

4.1.4 Air - Void

Air Void Results		
Set	Batch	Value
1	Ref - 1 CN 2 -50 CN 4 - 50	1.4 % 2 % 1.85 %
2	Ref - 1 CN 2 -50 CN 4 - 50	1.9 % 1 % 2.3 %

Table 4.1.4: Air Void results

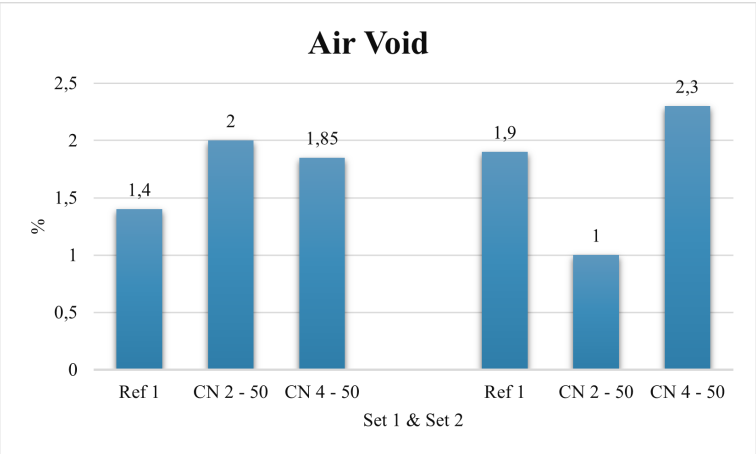


Figure 4.1.4: Air Void, Set 1

In Set 1 the air void volume is higher with an addition of CN.
Set 2.2, however, shows no connection between CN and air void volume.
B8 shows a significantly lower amount of air than B7 and B9. As mentioned in paragraph **2.1.6 Air**, non-entrained concrete usually contains between 1% and 2% entrapped air. All batches show a normal amount of air.

4.2 Compressive Strength

As mentioned in **3.4.1 Compressive Strength**, the compressive strength was measured according to Scope of Work, **Appendix C**

4.2.1 Results of Compressive Strength Set 1

Table of Compressive Strength Results, Set 1		
Day	Cube	Strength [kN]
1	0%_01	0
	0%_02	0
	2%_01	0
	2%_02	0
	4%_01	0
	4%_02	0
2	0%_01	36.252
	0%_02	37.1181
	2%_01	36.983
	2%_02	0
	4%_01	40.2044
	4%_02	41.3241
7	0%_01	155.9341
	0%_02	166.3549
	2%_01	172.4224
	2%_02	173.767
	4%_01	173.0301
	4%_02	147.2128
28	0%_01	457.2656
	0%_02	455.3581
	2%_01	492.5707
	2%_02	487.8581
	4%_01	505.1274
	4%_02	503.335

Table 4.2.1: Compressive Strength Results, Set 1

Figure 4.2.1: Strength Development, Set 1

As Set 1 showed little to no compressive strength on day 1, it became clear that the mix design needed adjusting. See paragraph **5.2.1 Change of Mix Design - Set 1**.

On day 2 the CN 4 - 50 cubes showed greater strength then the reference. The second parallel of the CN 2 - 50 cubes experienced an error when demoulding, which led to no compressive strength. The first parallel of the CN 2 - 50 cubes showed no change in compressive strength compared to the reference.

On day 7 the CN 2 - 50 cubes showed greater strength than the reference. Only one of the parallels of the 4 - 50 cubes showed greater strength.

By day 28 all samples containing CN showed greater strength then the reference.

Even though there were an error in Set 1 - Design Mix, the concrete cubes did reach an acceptable level of compressive strength by day 28.

4.2.2 Results of Compressive Strength Set 2.2

Table of Compressive Strength Results, Set 2		
Day	Cube	Strength [kN]
1	0%_01	10
	0%_02	13
	2%_01	36.7707
	2%_02	37.1992
	4%_01	29.9958
	4%_02	31.194
2	0%_01	112.6107
	0%_02	113.2791
	2%_01	108.9682
	2%_02	100.7073
	4%_01	103.8669
	4%_02	107.8225
7	0%_01	291.1765
	0%_02	299.0573
	2%_01	289.8531
	2%_02	297.9297
	4%_01	267.193
	4%_02	269.57
28	0%_01	546.4319
	0%_02	518.4794
	2%_01	560.1643
	2%_02	552.8353
	4%_01	693.2418
	4%_02	691.8262

Table 4.2.2: Compressive Strength, Set 2.2

Figure 4.2.2: Set 2.2: Compressive Strength

On day 1 the cubes containing CN showed a significantly higher compressive strength than the reference. CN 2 - 50 showed a slightly higher value then CN 4 - 50.

On day 2, however, the grading of compressive strength had shifted. The reference showed greater compressive strength than both samples containing CN.

On day 7, the reference and CN 2 - 50 showed approximately the same level of compressive strength. CN 4 - 50 gave weaker results.

Due to a source of error, see **5.5Sources of Error**, the results from day 28 are not taken into consideration. However, the reference and CN 2 - 50 did cure in the same circumstances, and CN 2 - 50 did reach a higher level of compressive strength than the reference.

On day 28, all results reached an acceptable level of compressive strength.

4.3 Hydration

The level of hydration was measured by conducting an isothermal calorimetry test and a thermogravimetric analysis.

4.3.1 Isothermal Calorimetry

The hydration development of different CN pastes were plotted as a function of time and hydration rate (mW/g binder). See **Figure 4.3.1**. The cumulative heat development was plotted as a function of time and J/g powder, see **Figure 4.3.3**. Note that the first strong peak out of scale is due to the sample being warmer than the background due to mixing energy, and so the curves in **Figure 4.3.1** should not be considered as terms of hydration within the first 45 minutes.

The collected data showed great similarity to prior research conducted by Harald Justnes [16] [17] . Therefore some of the same conclusions have been drawn.

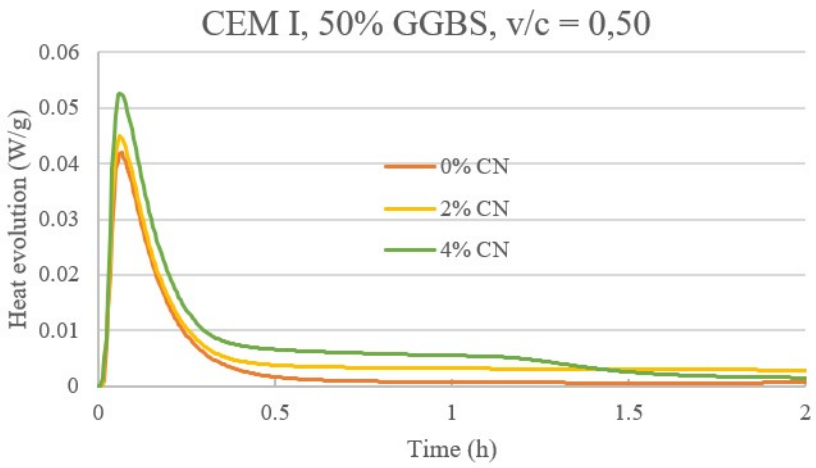


Figure 4.3.1: Heat Evolution During the First 2h

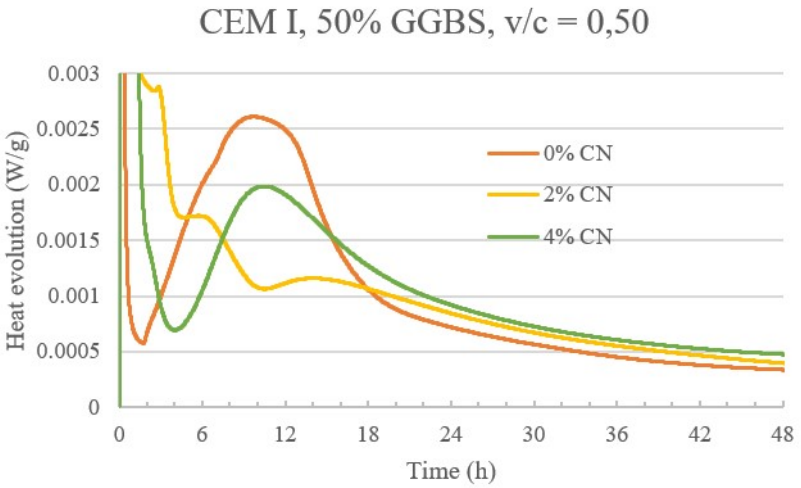


Figure 4.3.2: Heat Evolution During the First 48h

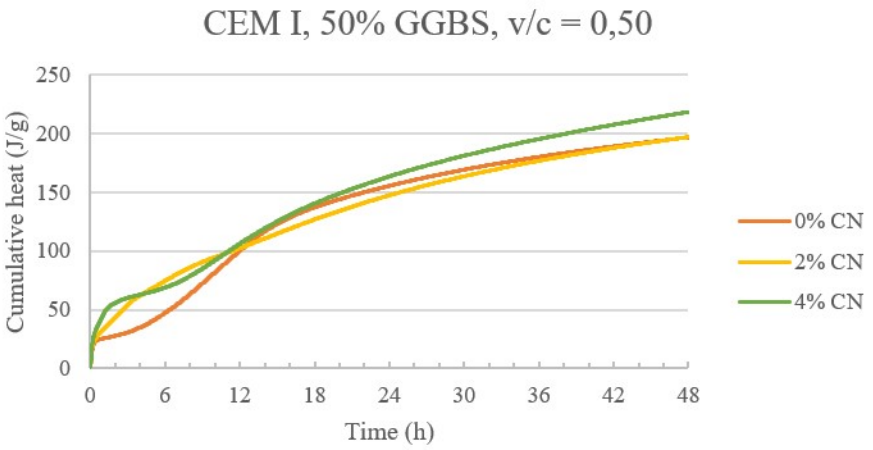


Figure 4.3.3: Cumulativ Heat During the First 48h

The reference (0% CN) shows a binomal curve, **Figure 4.3.2**.
The beginning of the first peak indicates the starts of hydration of the main mineral alite (Ca_3SiO_5). Alite desolves incongruently and releases calcium minerals (Ca^{2+}) and hydroxide-ions (OH^-) to the pores whilst leaving a rich silicat layer behind. The consentration of calcium and hydroxide can accumulate to an oversaturated level relative to calcium hydroxide. When calcium hydroxide finally starts to crystallize, there is a burst in renewed alite hydration, which leads to the first broad peak.
The initial setting time, when the paste is no longer a fluid, is just after the hydration rate acceleration and the final setting time (when the cement has lost all plasticity) is just before the curve starts to bend off .

The general alite acceleration caused by calcium nitrate can be interpreted as follows. As the concentration of calcium ions in the mixing water increases , there is less alite hydration needed to reach to reach supersaturation with respect to calcium hydroxide and on-set of its crystallization.
$Ca_3Al_2O_6$ is the fastest reacting cement mineral, and is often simply called the aluminate phase.

$$Ca_3Al_2O_6\,(s) + 3\,CaSO_4{\cdot}2H_2O\,(aq) + 26\,H_2O = Ca_3Al_2O_6{\cdot}3CaSO_4{\cdot}32H_2O\,(s) \tag{4.1}$$

As alite reacts, more surface of $Ca_3Al_2O_6$ in the cement grain will be exposed, and after a while there will be more alimunate reacted than there is gypsum to stabalize ettringite. The second peak of the reference, illustarted in **Figure 4.3.2**, takes place after approximately two hours. This peak is caused by a C-H-S reaction that occurs after a dormant period while it usually forms a shoulder caused by **Equation 4.2**

$$2\,Ca_3Al_2O_6\,(s) + Ca_3Al_2O_6{\cdot}3CaSO_4{\cdot}32H_2O\,(s) + 4\,H_2O = 3\,Ca_3Al_2O_6{\cdot}CaSO_4{\cdot}12H_2O\,(s) \tag{4.2}$$

In comparison to the reference, the CN 2 - 50 has a sharp early peak and the broad peak is moved to shorter time. Whilst for the CN 4 - 50 there is an even earlier sharp peak and the broad peak is moved later in time compared to the reference.
The cement starts the production of calcium hydroxide earlier, therefore the GGBS is also exposed to calcium hydroxide earlier, and will develop strength at an earlier stage.

The cumulative heat is believed to be correlated to the compressive strength. The mixes containing CN have a higher cumulative heat at 12h, is closer to the reference at 24 h, and deviates from the reference with a higher value at 48h and beyond. Prior research conducted by Harald Justnes [17] showed a lack of response at day 1, and is why CN is not considered to be a hardening accelerator. However, the results from this research indicates differently.

4.3.2 Thermogravimetric analysis

A thermogravemetric analysis is weightloss as a function of temperature.

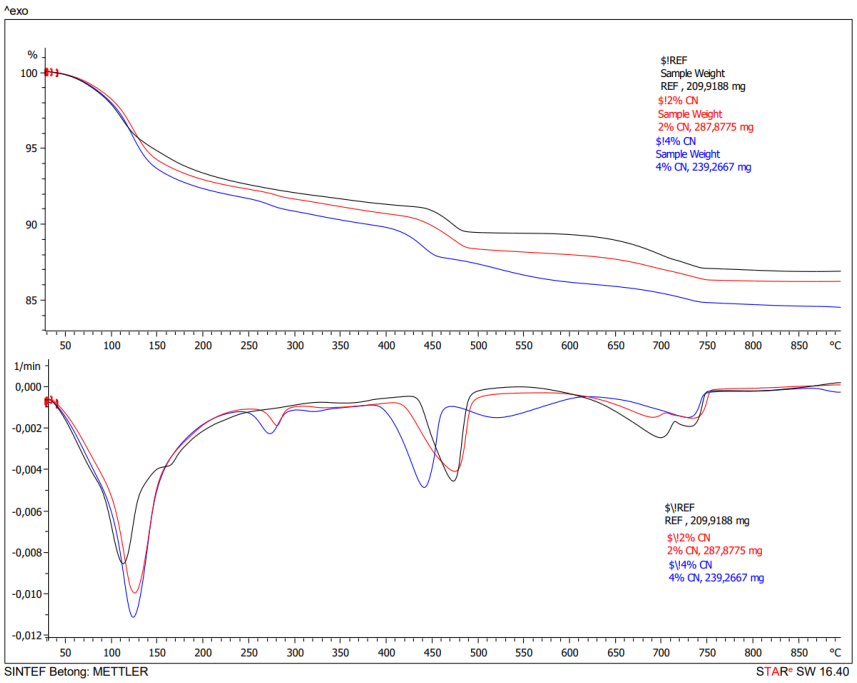


Figure 4.3.4: Termogravimetri Results

The top curve is the actual weightloss, and the bottom curve is simply the derivative of the top curve, weightloss therefore appears as «top» and «bottoms». All weightloss "tops" are due to water, except the last one which is due to carbon dioxide.

The first «top», at approximatly 120 degrees, shows the decomposition of Calsium-silicate-hydrate (C-S-H), the primary reaction product of cement hydration, and ettringite.The samples containing CN experiences a bigger weightloss than the reference. This can be explained by an incresed amount of both C-S-H and ettringite where CN stabilieses ettringites.

At 270 degrees the reference does not move, due to dehydration of a reaction of calsium aluminate-nitrate-hydrate in CN.
A decomposistion of calsium hydroxide occurs around 400-500.
At around 650-800 there is a splitting of calsium carbonate.

Calcium carbonate either originates from limestone mortared into the cement (crystallines and decomposes at the highest temperature). Or the cement has absorbed CO^2 from the air (carbonation) during preparation (higher surface and decomposes at a slightly lower temperature).

CHAPTER

FIVE

DISCUSSION

This chapter will state the significance of the compressive strength test results. It will also include a further discussion on why there was a change of mix design, as well as the consequences and the sources of error.

5.1 Level of Significance

Level of significance has been calculated to conclude whether or not the change of strength is effected by CN.
Due to only testing two parallels, the level of significance was calculated by multiplying the reference's standard deviation by two. All calculations were completed in Microsoft Excel.

5.1.1 Significance of Set 1

Table of Significance, Set 1		
Day	SD	Significance
1	0	0
2	0.43305	0.8661
7	5.2104	10.4208
28	0.95375	1.9075

Table 5.1.1: Level of Significance, Set 1

Due to **5.5 Sources of Error - software error** all results from day 1 were taken out of consideration, and level of significance was therefore marked as invalid.

Day 2 compressive strength showed one insignificant sample of CN 2 - 50, and one invalid sample, see **5.5 Source of Error - Human Error**. CN 4 - 50 show an significant increase of strength.

Table of Significance, Set 1			
Day	Cube	Strength	Significance
1	0%_01	0	
	0%_02	0	
	2%_01	0	INVALID
	2%_02	0	INVALID
	4%_01	0	INVALID
	4%_02	0	INVALID
2	0%_01	36.252	
	0%_02	37.1181	
	2%_01	36.983	NOT OK
	2%_02	0	INVALID
	4%_01	40.2044	OK
	4%_02	41.3241	OK
7	0%_01	155.9341	
	0%_02	166.3549	
	2%_01	172.4224	OK
	2%_02	173.767	OK
	4%_01	173.0301	OK
	4%_02	147.2128	NOT OK
28	0%_01	457.2656	
	0%_02	455.3581	
	2%_01	492.5707	OK
	2%_02	487.8581	OK
	4%_01	505.1274	OK
	4%_02	503.335	OK

Table 5.1.2: Significance, Set 1

On test day 7 both samples of CN 2 - 50 were significant. One parallel of CN 4 - 50 showed a significant increase in compressvie strength, while the other parallel did not.

By day 28 all samples showed a significant increase of compressive strength.

5.1.2 Significance of Set 2.2

Table of Significance, Set 2.2		
Day	SD	Significance
1	1.5	3
2	0.3342	0.6684
7	3.9404	7.8808
28	13.97625	27.9525

Table 5.1.3: Level of Significance, Set 2.2

Table of Significance, Set 2.2			
Day	Cube	Strength	Significance
1	0%_01	10	
	0%_02	13	
	2%_01	36.7707	OK
	2%_02	37.1992	OK
	4%_01	29.9958	OK
	4%_02	31.194	OK
2	0%_01	112.6107	
	0%_02	113.2791	
	2%_01	108.9682	OK
	2%_02	100.7073	OK
	4%_01	103.8669	OK
	4%_02	107.8225	OK
7	0%_01	291.1765	
	0%_02	299.0573	
	2%_01	289.8531	OK
	2%_02	297.9297	NOT OK
	4%_01	267.193	OK
	4%_02	269.57	OK
28	0%_01	546.4319	
	0%_02	518.4794	
	2%_01	560.1643	NOT OK
	2%_02	552.8353	NOT OK
	4%_01	693.2418	OK
	4%_02	691.8262	OK

Table 5.1.4: Significance, Set 2.2

Compressive strength results from day 1 showed a significant increase of strength for all samples containing CN.

Compressive strength results from day 2 showed a significant decrease of strength for all samples containing CN.

On day 7 one CN 2 - 50 sample did not show a significant change of strength. The other samples however, showed a significant decrese of strength.

Results from day 28 are not taken into consideration due to **5.5 Source of Error - Temperature During Curing**. However, the reference and CN 2 - 50 did cure under the same circumstances, and CN 2 - 50 did not show a significant increase of strength.

5.2 Change of Mix Design

Originally there were made three mix designs, one for each concentration of CN. Testing and moulding revealed a necessity of changing the mix design, due to several causes of error introduced in this paragraph. The proportioning was adjusted two times, and in total there were made nine mix designs.

5.2.1 Set 1

Set 1, **Appendix A.1**, was adjusted to a new mix of design, Set 2.1, **Appendix A.4**.

5.2.1.1 Silica Fume and GGBS

After consulting with Harald Justnes from SINTEF, and Kåre Brottveit Olsby and Thomas Uhlving from NTNU, the mix design was changed.

Blastfurnace slag is not considered pozzolanic in general, but rather a latent hydraulic additive that needs to be activated by cement or alkali hydroxides. [17] When the alkali, present in the cement, activates the particles in GGBS, hydration products are formed. Silica Fume is a highly pozzolanic material that chemically reacts with calcium hydroxide. [1] When Silica Fume is added to the mixture, the effect of GGBS decreases as Silica Fume absorbs some of the initial pH. [31]
Both GGBS and Silica Fume is supposed to increase the compressive strength of concrete. However the strength development happens quicker for Silica Fume as it has a significantly bigger size of surface to react with other substances. Since GGBS reacts slower than silica Fume, some of the initial pH is already absorbed, which leads to a decrease in the effect of GGBS.

To ensure full effect of GGBS, Silica Fume was removed from set 2.

5.2.1.2 CEMI and GGBS ratio

When proportioning the mix design for Set 1, the cement:GGBS ratio was set to 1:2. This was adjusted to 1:1 in Set 2.1, as discussed with external supervisors at Yara.

5.2.2 Set 2.1 - Separated Sample

The mix design of Set 2.1 resulted in a separated sample. A separation happens when the fresh concrete is not able to retain its homogeneity, and there is a lack of stability. More specifically, separation occurs when the sum of internal friction and cohesion is too low to counteract the effect of the different densities of the materials.

Due to separation, the concrete batch could not be moulded for curing. The mix design required adjustments to get the correct composition.

To achieve the desired result, adjustments in the sand:gravel-ratio were performed. The ratio was altered from a 3:2, to a 2:1 sand:gravel-ratio. As well as adjusting the sand/gravel ratio, it was decided to withhold the use of SP.
The effect of these adjustments resulted in a new homogeneous sample, Set 2.2 **Appendix A7** .

5.3 Core Temperature in Set 1

In Set 1 it was decided to measure the degree of hydration by measuring core temperature in the curing concrete. After further research it became clear that while this could be used to give an approximate measure of the degree of hydration, it was not possible to use the curing heat to specify the exact degree of hydration as intended. This method of testing brings an unnecessary in-accuracy in determining the final heat, and thus obtaining a reliable correlation to a known degree of hydration [38].
Method of measuring degree of hydration was replaced with an isothermal caligrometri test and an thermogravometric analysis, conducted with the assistance of SINTEF. [17]

5.4 CEM I vs. CEM II

CEM I consist of 100% cement, whilst CEM II contain up to 35% cement replacement [18]
To uphold a high level of accuracy when conducting this research, it was decided to make use of CEM I in the mix design. By using CEM I one can decide the exact amount of cement replacement. GGBS was used as a cement replacement, see **Appendix C**.

5.5 Source of Error

Throughout this bachelor thesis there were detected several sources of error. In this paragraph it will be discussed which errors were made, how they occurred, and what consequences they caused.

5.5.1 Temperature During Curing

The concrete cubes cured in both too cold and too warm of a climate, in a water bath stored in a cold storage room at NTNU.
In the early curing stage the cold storage room was set on the agreed temperature of 5°C. After closer inspection it turned out that the measured temperature was somewhat unstable, which made the curing temperature difficult to measure. When measuring the room temperature the thermometer showed temperatures between 3 °C and 8°C.
When measuring the concrete cubes core temperature, it was observed a temperature of approximately 3 °C. Set 1 cured all 28 days in a cold climate.

On the 03/05/2023 the main fuse at the NTNU lab blew, which led to the cold storage room malfunctioning.
The concrete cubes being tested on day 28 from Set 2.2, was not removed from the cold storage room until 10/05/2023, when the students themselves returned to the lab for testing compressive strength. Thus, the last 7 days of curing, B7 and B8 cured in a temperature of 28 °C. B9 stayed in 28°C for the last 12 days of curing.

5.5.2 Scarce of Materials

- **Use of CEM II**
  When mixing Set 1, CEM II was used instead of CEM I. It was decided to conduct this replacement since the NTNU lab had a scarce of CEM I.
  Making use of CEM II does not have to be an issue as long as one make use of the same type of CEM when testing both the compressive strength, and the level of hydration. This adjustment also resulted in a more precise mix, see **5.4 CEM I vs. CEM II**

- **10L batches**
  When mixing Set 2.2, there was a scarce of GGBS. Thus, it was decided to reduce the batch volume to 10L instead of 15L.
  There is a chance that the stirring mechanism of PMat Zuclus 50L did not blend as well with a smaller batch.

5.5.3 Software Error

- **Test Xpert iii – v1.7**
  The software saving the data when measuring compressive strength, does not save data results 18kN. Therefore all cubes tested on day 1 from Set 1, har no viable compressive strength results.

- **CatMan AP 5.5.2**
  The software processing the core temperature data, did not succeed on saving the data on the computer's hardware.

5.5.4 Human Error

As with all manual labor, there is a risk of misalignment. This can occure when scaling the materials, spilling during transfer, inaccuracy of method etc. Exact examples of human errors that occurred are listed below.

- **Removal of formwork**
  The concrete cubes in Set 1 were exposed to damage whilst removing the formwork. The cubes were still soft on day 1 when using a mix design with both GGBS and Silica. Thus, exposing the cubes too soon led to cracking.

- **Prosjektering by Sverre Smeplass**
  When entering values in Prosjektering, the wrong assessment was made when deciding the different ratios and materials in the design mix.

CHAPTER

SIX

CONCLUSIONS

The effect of calcium nitrate on cement blended with blastfurnace slag (50/50) has been tested.

Calcium nitrate led to significantly higher strength at day 1 for the slag-blended concrete. Where CN 2 - 50 showed a higher value than CN 4 - 50.
This pattern in compressive strength is the same as the trend in the cumulative heat development from the isothermal calorimetry test.
24h results show an early production of calcium hydroxide which caused high early strength in the concrete.
However, on day 2 and 7, the compressive strength results showed a decreasing trend.
On day 28 calcium nitrate again showed greater strength, yet these results have not been taken into consideration, due to curing in a warmer climate.

CHAPTER

SEVEN

LIST OF FIGURES AND TABLES

LIST OF FIGURES

LIST OF TABLES

BIBLIOGRAPHY

[1] J. Skibsted A.M. Gajewicz P.J. McDonald A.C.A. Muller, K.L. Scrivener. *Influence of silica fume on the microstructure of cement pastes*. https://www.sciencedirect.com/science/article/pii/S0008884615001118. Accessed: 12.04.2023.

[2] Andreas Erlien Grefstad Adrian Adamski. *Partikkel-matriks modellering av fersk betong med hensyn til ønsket betongflyt*. 2022. Accessed: 05.05.2023.

[3] Mihlad Ahmadyar. *Ductility in Lightweigth Concrete with Fiber*. 2011. Accessed: 08.03.2023.

[4] American Concrete Association. *Permeability of Concrete*. https://www.concrete.org/topicsinconcrete/topicdetail/permeability%20of%20concrete?search=permeability%20of%20concrete. Accessed: 17.03.2023.

[5] Cementitious Slag Makers Association. *GGBS Concrete*. https://ukcsma.co.uk/ggbs-concrete/. Accessed: 14.03.2023.

[6] National Precast Concrete Association. *Air Entrainment versus Air Entrapment*. https://precast.org/2012/12/air-entrainment-versus-air-entrapment/. Accessed: 14.02.2023.

[7] Silica Fume Association. *What is Silica Fume?* https://www.silicafume.org/general-silicafume.html. Accessed: 18.02.2023.

[8] Nathional Ready Mixed Concrete Assosiation. *Concrete in Practice*. 2014. Accessed: 03.03.23.

[9] Ben Backus. *Air Content in Concrete Mix Design*. https://www.globalgilson.com/blog/air-content-test#:~:text=Most%20non%2Dair%2Dentrained%20concrete,unintentionally%20entrain%20even%20more%20air". Accessed: 08.03.2023.

[10] Benjamin E. Backus. *Concrete Air Testing Methods: Why, When, How: An In-Depth Look*. https://www.globalgilson.com/blog/air-content-test#:~:text=Most%20non%2Dair%2Dentrained%20concrete,unintentionally%20entrain%20even%20more%20air. Accessed: 13.04.2023.

[11] CEMEX. *Portland cement.* https://www.cemex.co.uk/bulk-portland-cement. Accessed: 17.02.2023.

[12] Espen Hamnes Paulsen Eirik Århaug, Johannes Tollak Dymbde. *Glidestøping med miljøbetong.* 2021. Accessed: 17.04.2023.

[13] Elkem. *What is Silica-Fume?* https://www.elkem.com/products/silicon/silica-fume/. Accessed: 18.02.2023.

[14] Perkin Elmer. *Thermogravimetric Analysis (TGA).* https://resources.perkinelmer.com/lab-solutions/resources/docs/faq_beginners-guide-to-thermogravimetric-analysis_009380c_01.pdf. Accessed: 05.03.2023.

[15] Center for Macromolecular Interactions. *Isothermal Titration Calorimetry.* https://cmi.hms.harvard.edu/isothermal-titration-calorimetry. Accessed: 05.03.2023.

[16] Harald Justnes Ina Pundienė Gintautas Skripkiūnas, Asta Kičaitė. *Effect of Calcium Nitrate on the Properties of Portland-Limestone Cement-Based Concrete Cured at Low Temperature.* 2021. Accessed: 06.05.2023.

[17] Harald Justnes. *Private communication.* 2023.

[18] Hatcrete. *What mix? CEM1 or CEM2 or CEM3?* https://www.picsuk.com/what-mix-cem1-or-cem2-or-cem3/#:~:text=Put%20SIMPLY%2C%20a%20CEM1%20mix,as%20ggbs%20%2F%20slag%20%2F%20PBF. Accessed: 10.05.2023.

[19] American Concrete Institue. *What is a pozzolan?* https://www.concrete.org/tools/frequentlyaskedquestions.aspx?faqid=688. Accessed: 19.02.2023.

[20] R. Bruce Prime Jeff Gotro. *Introduction to Thermogravimetric Analysis (TGA).* https://polymerinnovationblog.com/thermoset-characterization-part-12-introduction-thermogravimetric-analysis-tga/. Accessed: 02.04.2023.

[21] C.M. Patel M.V.Patel J.M Rami, C.D. Patel. *Thermogravimetric analysis (TGA) of some synthesized metal oxide nanoparticles.* https://www.sciencedirect.com/science/article/pii/S2214785320402718. Accessed: 19.03.2023.

[22] L.A. Pothan S. Thomas K.R. Rajisha, B. Deepa. *Thermomechanical and spectroscopic characterization of natural fibre composites.* https://www.sciencedirect.com/topics/materials-science/thermogravimetric-analysis. Accessed: 24.03.2023.

[23] Kristine Aase Lisa Aadnøy. *Glidestøping av miljøbetong.* https://uis.brage.unit.no/uis-xmlui/handle/11250/3006053,, 2022.

[24] Total Concrete Ltd. *Concrete Slump Test - Measuring the Workability of Concrete.* https://www.totalconcrete.co.uk/news/concrete-slump-tests-measuring-the-workability-of-concrete/#:~:text=A%20concrete%20slump%20test%20measures,it%20is%20poured%20on%20site. Accessed: 13.04.2023.

[25] Dina A. Emarah M. Anwar. *Pore Structure of Concrete Containing Ternary Cementitous Blends.* https://www.sciencedirect.com/science/article/pii/S2590048X19300196#:~:text=In%20cement%2Dbased%20materials%2C%20the,arranged%20and%20sized%20%5B3%5D. Accessed: 27.04.2023.

[26] MAPEI. *DYNAMON SX23.* https://cdnmedia.mapei.com/docs/librariesprovider60/products-documents/1_06874_dynamon-sx-23-_en-no_5bdd6f07fb7d46c3b6397fdf9dcab7b1.pdf?sfvrsn=3de4e49d_0. Accessed: 06.03.2023.

[27] Heidelberg materials. *Anleggsement FA.* https://www.sement.heidelbergmaterials.no/en/anleggsementFA_eng. Accessed: 17.02.2023.

[28] Heidelberg materials. *Industrisement.* https://www.sement.heidelbergmaterials.no/en/industrisement_eng. Accessed: 17.02.2023.

[29] Ninjo Neuhaus. *Concrete Setting Accelerator.* https://www.yara.com/industrial-nitrogen/concrete-additives/concrete-setting-accelerator/. Accessed: 21.01.2023.

[30] J. Ahmed Naqash P. Narasimha Reddy. *Development of high early strength in concrete incorporating alccofine and non-chloride accelerator.* https://link.springer.com/article/10.1007/s42452-019-0790-z. Accessed: 07.03.2023.

[31] A. P. Shashikala P. Saranya, Praveen Nagarajan. *Eco-friendly GGBS Concrete: A State-of-The-Art Review.* 2017. Accessed: 14.04.2023.

[32] Malvern Panalytical. *Isothermal Titration Calorimetry.* https://www.malvernpanalytical.com/en/products/technology/microcalorimetry/isothermal-titration-calorimetry. Accessed: 09.03.2023.

[33] Todd Rudolph Pete Haug. *How to cure concrete in cold conditions.* https://www.ayresassociates.com/how-to-cure-concrete-in-cold-conditions/. Accessed: 14.03.2023.

[34] F.M. León-Martínez P.F. de J. Cano-Barrita. *Biopolymers with viscosity-enhancing properties for concrete.* https://www.sciencedirect.com/topics/materials-science/admixture. Accessed: 26.02.2023.

[35] John M. Scanlon Robert J. Ryan. *Accelerating Admixtures for Cold Climate Weather Concreting*, https://www.concreteconstruction.net/how-to/materials/accelerating-admixtures-for-cold-weather-concreting_o, Accessed: 14.04.2023.

[36] SINTEF. *Kvalitetskontroll av fersk betong.* https://www.byggforsk.no/dokument/286/kvalitetskontroll_av_fersk_betong. Accessed: 13.04.2023.

[37] Civil Sir. *Unit Weight of Concrete in kg/m3, kg/ft3, kN/m3, lbs/ft3 and lbs/in3.* https://civilsir.com/unit-weight-of-concrete/. Accessed: 13.04.2023.

[38] S. Smeplass K.O. Kjellsen E.J. Sellvold J. Lindgård R. Cepuritis R. Myrdal Ø. Bjøntegaard M. Geiker S.Jacobsen (Editor), M. Maage. *Concrete Technology.* NTNU, 2023.

[39] Cementitious slag makers association. *What is GGBS?* https://ukcsma.co.uk/what-is-ggbs/. Accessed: 23.03.2023.

[40] Sverre Smeplass. *Powerpoint, lecture.*

[41] GCP Applied Technologies. *Concrete Mix design.* https://gcpat.com/en/concrete/mix-design. Accessed: 05.03.2023.

[42] Brian Walker. *Predicting Fresh Concrete Temperatures.* https://www.concreteconstruction.net/how-to/concrete-production-precast/predicting-fresh-concrete-temperatures_o. Accessed: 13.04.2023.

[43] Yiluo Zhang Yanshun Jia Yulang Zhao, Ying Gao. *Effect of fines on the drying crack resistance of composite soil.* https://www.researchgate.net/figure/Grain-size-distribution-curve-of-natural-gravel-soil_fig3_323227136. Accessed: 27.04.2023.

CHAPTER

EIGHT

APPENDICES AND ATTACHMENTS

APPENDIX

A

MIX DESIGNS

Blandeskjema SKANSKA

Prosjekt	Bachelor thesis - NitCal 0%
Reseptnummer	Resept A (slump 100mm)
Tilsiktet kvalitet	B35 M60

Blandevolum	15 liter
Dato:	
Tidspunkt for vanntilsetning:	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	116,5	1,748			1,748	
0	0,0	0,000			0,000	
Elkem Microsilica	20,3	0,304	0,0	0,000	0,304	
Normineral flyveaske	0,0	0,000			0,000	
GGBS	253,3	3,800			3,800	
Fritt vann	138,6	2,079		-0,059	2,021	2,115
Absorbert vann	6,3	0,094			0,094	
Årdal 0/8 mm nat. vask.	1215,0	18,224	0,0	0,000	18,224	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	653,6	9,803	0,0	0,000	9,803	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	5,1	0,076	77	0,059	0,076	
Nitcal	0,0	0,000	50	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning	10,33				
Synkmål	230				
Utbredelsesmål					
Luft	1,4				
Densitet					

Blandeskjema

SKANSKA

Prosjekt	Bachelor thesis - Nitcal 2%
Reseptnummer	Resept A (slump 100mm)
Tilsiktet kvalitet	B35 M60

Blandevolum	15 liter
Dato:	
Tidspunkt for vanntilsetning:	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	114,7	1,720			1,720	
	0,0	0,000			0,000	
Elkem Microsilica	19,9	0,299	0,0	0,000	0,299	
Normineral flyveaske	0,0	0,000			0,000	
GGBS	249,2	3,739			3,739	
Fritt vann	136,4	2,046		-0,132	1,913	2,007
Absorbert vann	6,3	0,094			0,094	
Årdal 0/8 mm nat. vask.	1215,0	18,224	0,0	0,000	18,224	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	653,6	9,803	0,0	0,000	9,803	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	5,0	0,075	77	0,058	0,075	
Nitcal	10,0	0,150	50	0,075	0,150	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

Delark "Blandeskjema"

Blandeskjema

SKANSKA

Prosjekt	Bachelor thesis - Nitcal 4%
Reseptnummer	Resept A (slump 100mm)
Tilsiktet kvalitet	B35 M60

Blandevolum	15 liter
Dato:	
Tidspunkt for vanntilsetning:	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	112,8	1,692			1,692	
	0,0	0,000			0,000	
Elkem Microsilica	19,6	0,294	0,0	0,000	0,294	
Normineral flyveaske	0,0	0,000			0,000	
GGBS	245,3	3,679			3,679	
Fritt vann	134,2	2,013		-0,204	1,809	1,903
Absorbert vann	6,3	0,094			0,094	
Årdal 0/8 mm nat. vask.	1215,0	18,224	0,0	0,000	18,224	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	653,6	9,803	0,0	0,000	9,803	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	4,9	0,074	77	0,057	0,074	
Nitcal	19,6	0,294	50	0,147	0,294	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

Delark "Blandeskjema"

Blandeskjema

SKANSKA

Prosjekt	Betongteknologi 1 Lab øving
Reseptnummer	Resept 0% (slump 200mm)(justnes)
Tilsiktet kvalitet	B45 M60

Blandevolum	15 liter
Dato:	
Tidspunkt for vanntilset	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m^3	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	177,1	2,656			2,656	
GGBS	177,1	2,656			2,656	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
0	0,0	0,000			0,000	
Fritt vann	159,4	2,390		-0,082	2,309	2,404
Absorbert vann	6,4	0,095			0,095	
Årdal 0/8 mm nat. vask.	1100,2	16,504	0,0	0,000	16,504	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	762,9	11,443	0,0	0,000	11,443	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	7,1	0,106	77	0,082	0,106	
Nitcal	0,0	0,000	50	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					

Blandeskjema

SKANSKA

Prosjekt	Betongteknologi 1 Lab øving
Reseptnummer	Resept 2% (slump 200mm)(justnes)
Tilsiktet kvalitet	B45 M60

Blandevolum	15 liter
Dato:	
Tidspunkt for vanntilset	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m^3	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	173,1	2,597			2,597	
GGBS	173,1	2,597			2,597	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
0	0,0	0,000			0,000	
Fritt vann	155,8	2,337		-0,184	2,154	2,249
Absorbert vann	6,4	0,095			0,095	
Årdal 0/8 mm nat. vask.	1100,2	16,504	0,0	0,000	16,504	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	762,9	11,443	0,0	0,000	11,443	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	6,9	0,104	77	0,078	0,104	
Nitcal	13,9	0,208	50	0,203	0,208	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					

Blandeskjema

SKANSKA

Prosjekt	Betongteknologi 1 Lab øving
Reseptnummer	Resept 4% (slump 200mm)(Justnes)
Tilsiktet kvalitet	B45 M60

Blandevolum	15 liter
Dato:	
Tidspunkt for vanntilset	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	169,4	2,541			2,541	
GGBS	169,4	2,541			2,541	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
0	0,0	0,000			0,000	
Fritt vann	152,4	2,287		-0,282	2,005	2,100
Absorbert vann	6,4	0,095			0,095	
Årdal 0/8 mm nat. vask.	1100,2	16,504	0,0	0,000	16,504	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	762,9	11,443	0,0	0,000	11,443	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	6,8	0,102	77	0,078	0,102	
Nitcal	27,1	0,407	50	0,203	0,407	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					

Blandeskjema

SKANSKA

Prosjekt	Betongteknologi 1 Lab øving
Reseptnummer	Resept 0% (slump 200mm)(justnes)
Tilsiktet kvalitet	B35 M60

Blandevolum	10 liter
Dato:	
Tidspunkt for vanntilsetning:	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	175,1	1,751			1,751	
GGBS	175,1	1,751			1,751	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
0	0,0	0,000			0,000	
Fritt vann	157,6	1,576		-0,027	1,549	1,611
Absorbert vann	6,2	0,062			0,062	
Årdal 0/8 mm nat. vask.	1253,5	12,535	0,0	0,000	12,535	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	616,8	6,168	0,0	0,000	6,168	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	3,5	0,035	77	0,027	0,035	
Nitcal	0,0	0,000	50	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

Delark "Blandeskjema"

Blandeskjema

SKANSKA

Prosjekt	Betongteknologi 1 Lab øving
Reseptnummer	Resept 2% (slump 200mm)(justnes)
Tilsiktet kvalitet	B35 M60

Blandevolum	10 liter
Dato:	
Tidspunkt for vanntilsetning:	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	171,2	1,712			1,712	
GGBS	171,2	1,712			1,712	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
0	0,0	0,000			0,000	
Fritt vann	154,1	1,541		-0,095	1,446	1,508
Absorbert vann	6,2	0,062			0,062	
Årdal 0/8 mm nat. vask.	1253,5	12,535	0,0	0,000	12,535	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	616,8	6,168	0,0	0,000	6,168	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	3,4	0,034	77	0,026	0,034	
Nitcal	13,7	0,137	50	0,068	0,137	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

Delark "Blandeskjema"

Blandeskjema

SKANSKA

Prosjekt	Betongteknologi 1 Lab øving
Reseptnummer	Resept 4% (slump 200mm)(Justnes)
Tilsiktet kvalitet	B45 M60

Blandevolum	10 liter
Dato:	
Tidspunkt for vanntilsetning:	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Standard FA	0,0	0,000			0,000	
Norcem Anlegg	167,5	1,675			1,675	
GGBS	167,5	1,675			1,675	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
0	0,0	0,000			0,000	
Fritt vann	150,7	1,507		-0,160	1,348	1,410
Absorbert vann	6,2	0,062			0,062	
Årdal 0/8 mm nat. vask.	1253,5	12,535	0,0	0,000	12,535	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	616,8	6,168	0,0	0,000	6,168	
Årdal 16/22 mm	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Mapei Dynamon SX-23	3,3	0,033	77	0,026	0,033	
Nitcal	26,8	0,268	50	0,134	0,268	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
	0,0	0,000			0,000	
	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

Delark "Blandeskjema"

APPENDIX

B

SAFETY DATA SHEET

GGBS
Material Safety Data Sheet (MSDS)

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY

1.1 Product identifier

1.1.1 Identification on the label / tradename: Ground Granulated Blast furnace Slag GGBS

1.1.2 Additional terms: Slags, ferrous metal, blast furnace (granulated)

1.1.3 REACH Registration number: 01-2119487456-25

1.2 Relevant identified uses of the substance or mixture and uses advised against

1.2.1 Identified uses: Constituent of standard cements (EN 197-1) and special binders, concrete preparation, road construction

1.2.2 Uses advised against: None

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture:

This substance does not meet the requirements for classification as dangerous under both the EU Dangerous Substances (67/548/EEC) Directive and secondly according to the Classification, Labelling and Packaging of substances and mixtures (CLP) regulations (EC 1272/2008).

2.2 Other hazards:

Dust of granulated slag can act as an irritant and cause mechanical irritation to the eyes and respiration system.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Substance related information:
Slags, ferrous metal, blast furnace
EG-Nr.: 266-002-0 CAS-Nr.: 65996-69-2
complex Ca-Mg- Al- silicate composition

Further information:
Granulated slag is a vitrified substance, which is a byproduct of iron production in a blast furnace. The structure of the granulated slag depends on the temperature during cooling.

4. FIRST AID MEASURES

4.1 In case of inhalation:

Move affected person into fresh air. Seek medical advice if irritation persists.

4.2 In case of skin contact:

Wash with soap and water.

4.3 In case of eye contact:

Rinse the eyes with water with the eyelids open.

4.4 In case of ingestion:

Seek medical advice if irritation persists. Rinse mouth and drink plenty of water.

5. FIRE-FIGHTING MEASURES

5.1 Extinguishing media:

Product itself does not burn. Coordinate fire-fighting measures with surrounding.

5.2 Special hazards arising from the substance or mixture:

None

5.3 Advice for firefighters:

Not applicable

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions:

Avoid dust dispersion.

6.2 Environmental precautions:

Not necessary

6.3 Methods for cleaning up:

Pick up mechanically, avoid disturbing dust. Use dust reducing cleaning method.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

7.1.1 Advices on safe handling: Avoid dust dispersion. Where applicable keep dust wet. In closed areas provide adequate ventilation to prevent dust inhalation.

7.1.2 Technical measures: In case of further handling with foreseeable high dust dispersion, use for example an exhaust ventilation with filter or a closed system.

7.1.3 Advice on general occupational hygiene: Do not eat, drink, smoke or take snuff while working. Wash hands before breaks and after work.

7.2 Conditions for safe storage, including any Incompatibilities:

None

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

8.1 Control parameters

Occupational exposure limits:			Limit value - short term ml/m3 mg/m³
CAS-No.	Name	Limit value - 8 h ml/ m3 mg/m³	
	Dust, respirable	3	6
	Dust, inhalable	10	20

8.1.2 Additional hints on exposure limits:

Source (German legislation): (no EU-Value available!) TRGS 900: "Arbeitsplatzgrenzwerte". Observe in addition the national legislative regulations!

8.1.3 DNEL and PNEC values:

No specific substance related threshold can be derived.

8.2 Exposure controls

8.2.1 Occupational exposure controls:

Refer to no. 7.

8.2.2 Respiratory protection:

In case of high dust concentration: EN149 FFP2 filter.

8.2.3 Hand protection:

Check the resistance to chemicals of the protective gloves together with the supplier of the gloves. Use only gloves conform to 89/686/EEC. Wear duration at permanent or occasional contact: gloves made of fabric coated with nitrile rubber Breakthrough time (maximal wear duration): > 480 min.

8.2.4 Eye protection:

At appearance of dust: safety glasses.

8.2.5 Suitable protective clothing:

Use usual working clothes.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

Physical state:	Granulated: 0/5 mm
Colour:	Grey
Odour	Odourless
pH Value:	10 -12 (DEV-S4-eluate according EN 12457-4)
Melting point/freezing point:	> 1000°C
Density	Approx. 2.4 - 3 g/cm³ (20 °C)
Water solubility:	<1 g/l
Flash point:	N.A. (substance is inorganic)
Other information:	None

10. STABILITY AND REACTIVITY

10.1 Conditions to avoid:

None

10.2 Incompatible materials:

None

10.3 Hazardous decomposition products:

None

11. TOXICOLOGICAL INFORMATION

11.1 Acute effects

11.1.1 Acute toxicity:

Oral: tested substance GBS
OECD Guideline 401, Wistar rat LD50 > 2000 mg/kg CSR

Inhalative: tested substance GGBS
OECD Guideline 403, Wistar rat LC50 (powder) (4h) > 5234 mg/m³ CSR

11.1.2 Irritant-/corrosive effects:

Skin: tested substance ABS
Acute irritant effect, OECD 404, New Zealand White rabbit result: not irritant CSR

Eye: tested substance ABS
Acute irritant effect, OECD 405, New Zealand White rabbit result: not irritant CSR

11.2 Sensitisation:

Skin: tested substance ABS
OECD 406, Dunkin-Hartley guinea pig result: not sensitive CSR

11.3 Repeated dose toxicity (subacute, subchronic, chronic): n.d.a.

11.4 CMR effects (carcinogenicity, mutagenicity and toxicity for reproduction):

Mutagenicity: tested substance ABS
Reversed mutation test, EU method B.13/14,
Salmonella typhimurium result: no mutagenic effect CSR

Mutagenicity: tested substance ABS
Mamman cell gene mutation test, EU method B.17,
Chinese hamster lung fibroblast (V79) result: no mutagenic effect CSR

11.5 Experiences made in practice:

None

11.6 Additional information:

Due to “read across”, results from other slag types are referred to

12. ECOLOGICAL INFORMATION

12.1 Toxicity:

Short-term fish toxicity, tested substance GBS
OECD 203, Leuciscus idus
LC0 (96 h) > 1000 g/l
LC50 (96 h) > 1000 g/l CSR

Short-term toxicity aquatic invertebrates, tested substance GBS
OECD 202, Daphnia magna
EC0 (48 h)) > 1000 g/l
EC50 (48 h) > 1000 g/l CSR

Algae toxicity, tested substance GBS
OECD 201, Scenedesmus subspicatus
IC10 (72 h) > 100 g/l
IC50 (72 h) > 100 g/l CSR

Micro organism toxicity, tested substance ABS
OECD 209, activated sludge

EC_{10}	(3 h)	> 10 g/l	
EC_{50}	(3 h)	> 10 g/l	
EC_{100}	(3 h)	> 10 g/l	CSR

Long-term toxicity aquatic invertebrates, tested substance ABS
OECD 211, Daphnia magna

EC_{10}	(21 d)	5 g/l	
EC_{20}	(21 d)	> 5 g/l	
EC_{50}	(21 d)	> 5 g/l	CSR

12.2 Persistence and degradability:

n.a

12.3 Bioaccumulative potential:

No evidence for bioaccumulation potential.

12.4 Mobility in soil:

n.d.a.

12.5 Results of PBT assessment:

n.d.a.

12.6 Other adverse effects:

No negative ecological effects are expected according to the present state of knowledge.

12.7 Additional information:

Due to “read across”, results from other slag types are referred to.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods:

Granulated blast furnace slag can be recovered after spillage. In the case there is no further use, the slag can be disposed following local legislation.

13.2 List of proposed waste codes/waste designations in accordance with AVV (or EWC):

Waste classification due to trade and processing. Disposal is possible as follows: EWC-Code: 10 02 01: waste from the processing of slags.

14. TRANSPORT INFORMATION

14.1 Land transport (ADR/RID/CDG Road/ CDG Rail):

No hazardous material as defined by transport regulations.

14.2 Inland waterway craft (ADN/ADNR):

No hazardous material as defined by transport regulations.

14.3 Marine transport (IMO):

No hazardous material as defined by transport regulations.

14.4 Air transport (ICAO/IATA):

No hazardous material as defined by transport regulations.

15. REGULATORY INFORMATION

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

15.1.1 EU law:

None

15.1.2 National law:

See national legislation!

15.2 Chemical safety assessment:

Not necessary

16. OTHER INFORMATION

16.1 Documentation of changes:

*Data changed compared with the previous version. Revision of Material safety data sheet from 01.02.2011

16.2 Training instructions:

None

16.3 Recommended restrictions on use:

None

16.4 Further information:

Abbreviations:

n.d.a.	No data available
n.a.	Not applicable
ABS	Air-cooled blast furnace slag GBS = Granulated Blast furnace Slag
GGBS	Ground Granulated Blast furnace Slag
CSR	Chemical Safety Report Ferrous Slags

16.5 Sources

Disclaimer

The information in this Safety Data Sheet was believed to be correct at the time of issue. It does not, however, give assurances of product properties and establishes no contract legal rights.

If you have purchased this product for supply to a third party for use at work, it is your duty to take all necessary steps to ensure that any person handling or using the product is provided with the information in this sheet.

If you are an employer, it is your duty to tell your employees and others who may be affected of any hazards described in this sheet and any of the precautions which should be taken.

This Safety Data Sheet does not constitute the user's own assessment of workplace risk, and it is the user's sole responsibility to take all necessary safety precautions when using this product.

The product is to be used exclusively for the applications named in the technical leaflet or in the processing instructions. The receiver of our product is singularly responsible for adhering to existing laws and regulations.

For further information contact:

Hanson Uk
14 Castle Hill
Maidenhead
SL6 4JJ

Customer Services:

Tel: 01628 774 100
Email: cement@hanson.com

hanson.co.uk

Hanson
HEIDELBERGCEMENT Group

This Material Safety Data Sheet conforms to the requirements of ANSI Z400.1. - United States

Material Safety Data Sheet

NitCal K

1. Product and company identification

Product name	:	NitCal K
Product type	:	solid [Granular solid.]
Code	:	PA318G

Uses

Area of application	:	Industrial applications

Supplier

Supplier's details		Yara North America, Inc.

Address

Street	:	100 North Tampa Street, Suite 3200
Postal code	:	33602
City	:	TAMPA
Country	:	United States
Telephone number	:	+1 813 222 5700
Fax no.	:	+1 813 875 5735
e-mail address of person responsible for this SDS	:	Not available.
Emergency telephone number (with hours of operation)	:	Canutec Chemtrec 24-hours Emergency Response: 1-800-424-9300 24h

Responsible name

Safety & Regulatory	:	R. Lee
Technical	:	B. Easterwood

National advisory body/Poison Center

Name	:	The National Poisons Emergency number
Telephone number	:	1 800 222 1222
Validation date	:	00/00/0000
Print date	:	04/05/2013

2. Hazards identification

Emergency overview

Physical state	:	solid [Granular solid.]
Color	:	White.
Odor	:	Odorless.

Signal word	:	WARNING!
Hazard statements	:	HARMFUL IF SWALLOWED. CAUSES EYE IRRITATION.
Precautionary measures	:	Do not ingest. Avoid contact with eyes. Wash thoroughly after handling.
OSHA/HCS status	:	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Potential acute health effects

Inhalation	:	Exposure to decomposition products may cause a health hazard. Serious effects may be delayed following exposure.
Ingestion	:	Toxic if swallowed.
Skin	:	No known significant effects or critical hazards.
Eyes	:	Irritating to eyes.

Potential chronic health effects

Chronic effects	:	No known significant effects or critical hazards.
Carcinogenicity	:	No known significant effects or critical hazards.
Mutagenicity	:	No known significant effects or critical hazards.
Teratogenicity	:	No known significant effects or critical hazards.
Developmental effects	:	No known significant effects or critical hazards.
Fertility effects	:	No known significant effects or critical hazards.
Target organs	:	Not available.

Medical conditions aggravated by over-exposure	:	None known.

See toxicological information (section 11)

3. Composition/information on ingredients

Name	CAS number	%
Nitric acid, calcium salt (2:1)	10124-37-5	70 - 80

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Remarks : 76% Anhydrous Calcium Nitrate (CAS# 10124-37-5), 7% Potassium Nitrate (CAS# 7757-79-1), 0.8% Ammonium Nitrate and 16.2% Water (CAS# 7732-18-5).

European Union - Product description

91% Nitric acid, potassium calcium salt hydrate (CAS# 905593-70-6) and 9% Nitric acid, ammonium calcium salt (CAS#15245-12-2.

4. First aid measures

Eye contact	:	Rinse with plenty of running water. Check for and remove any contact lenses.
Skin contact	:	Wash with soap and water. Get medical attention if irritation develops.
Inhalation	:	If inhaled, remove to fresh air. Get medical attention if symptoms occur.
Ingestion	:	Wash out mouth with water. If material has been swallowed and the exposed person is conscious, give small quantities of water to drink. Do not induce vomiting unless directed to do so by medical personnel. Get

medical attention immediately.

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Wash contaminated clothing thoroughly with water before removing it, or wear gloves.

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled. In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

5. Fire-fighting measures

Flammability of the product : No specific fire or explosion hazard.

Extinguishing media

Suitable : Use flooding quantities of water for extinction.

Not suitable : Do NOT use chemical extinguisher or foam or attempt to smother the fire with steam or sand.

Special exposure hazards : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training.

Hazardous thermal decomposition products : Avoid breathing dusts, vapors or fumes from burning materials. In case of inhalation of decomposition products in a fire, symptoms may be delayed.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Special remarks on fire hazards : Non-flammable.

Special remarks on explosion hazards : None.

6. Accidental release measures

Personal precautions : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spilled material. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment (see Section 8).

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods for cleaning up

Small spill : Move containers from spill area. Vacuum or sweep up material and place in a designated, labeled waste container. Dispose of via a licensed waste disposal contractor.

Large spill : Move containers from spill area. Approach release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Vacuum

or sweep up material and place in a designated, labeled waste container. Dispose of via a licensed waste disposal contractor. Note: see section 1 for emergency contact information and section 13 for waste disposal.

7. Handling and storage

Handling : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Do not get in eyes or on skin or clothing. Do not ingest. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Empty containers retain product residue and can be hazardous. Do not reuse container. See also Section 8 for additional information on hygiene measures.

Storage : Store in accordance with local regulations. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Keep container tightly closed and sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental contamination. Keep away from: organic materials, oil and grease.

8. Exposure controls/personal protection

Occupational exposure limits

No exposure standard allocated.

Consult local authorities for acceptable exposure limits.

Engineering measures : No special ventilation requirements. Good general ventilation should be sufficient to control worker exposure to airborne contaminants. If this product contains ingredients with exposure limits, use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure below any recommended or statutory limits.

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Wash contaminated clothing before reusing. A washing facility or water for eye and skin cleaning purposes should be present.

Personal protection

Respiratory : Use a properly fitted, particulate filter respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator. Recommended: In case of inadequate ventilation wear respiratory protection. Filter P2 (EN 143)

Hands : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.
> 8 hours (breakthrough time): Protective gloves should be worn under normal conditions of use., Viton, neoprene

Eyes : Safety eyewear complying with an approved standard should be used

		when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts. chemical splash goggles. Recommended: CEN: EN166
Skin	:	Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Environmental exposure controls	:	Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

9. Physical and chemical properties

Physical state	:	solid [Granular solid.]
Flash point	:	Not determined.
Burning time	:	Not determined.
Burning rate	:	Not determined.
Auto-ignition temperature	:	Not determined.
Flammable limits	:	**Lower:** Not determined. **Upper:** Not determined.
Color	:	White.
Odor	:	Odorless.
pH	:	6.3 [Conc.: 110 g/l]
Boiling/condensation point	:	Not determined.
Sublimation temperature	:	Not determined.
Melting/freezing point	:	90 - 100 °C (194 - 212 °F)
Bulk density	:	1,100 kg/m3
Relative density	:	2.1 @ 20 °C (68 °F)
Vapor pressure	:	Not determined.
Odor threshold	:	Not determined.
Evaporation rate	:	Not determined.
Viscosity	:	**Dynamic:** Not determined.
	:	**Kinematic:** Not determined.
Solubility	:	Easily soluble in the following materials: cold water

10. Stability and reactivity

Chemical stability	:	The product is stable.
Conditions to avoid	:	Avoid contamination by any source including metals, dust and organic materials.
Incompatible materials	:	alkalis combustible materials reducing materials organic materials acids
Hazardous decomposition products	:	Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Possibility of hazardous reactions	:	Under normal conditions of storage and use, hazardous reactions will not occur.

11. Toxicological information

Information on toxicological effects

Acute toxicity

Product / ingredient name	Result	Species	Dose	Exposure	References
Nitric acid, calcium salt (2:1)					
	LD50 Oral	Rat - Female	500 mg/kg 423 Acute Oral toxicity - Acute Toxic Class Method	-	IUCLID 5
	LD50 Dermal	Rat	> 2,000 mg/kg OECD 402	-	IUCLID 5

Conclusion/Summary : Harmful if swallowed.

Chronic toxicity

Product / ingredient name	Result	Species	Dose	Exposure	References
Nitric acid, calcium salt (2:1)	Sub-acute NOAEL Oral	Rat	> 1000 mg/kg OECD 407	28 days	IUCLID 5

Conclusion/Summary : No known significant effects or critical hazards.

Irritation/Corrosion

Product / ingredient name	Result	Species	Score	Exposure	Observation	References
Nitric acid, calcium salt (2:1)	Eyes - Corrosive. OECD 405	Rabbit	4		-	

Conclusion/Summary

Skin : No known significant effects or critical hazards.

Eyes : Causes serious eye damage.

Respiratory : No known significant effects or critical hazards.

Sensitization

Conclusion/Summary

Skin : Not sensitizing

Respiratory : No known significant effects or critical hazards.

Carcinogenicity

Conclusion/Summary : No known significant effects or critical hazards.

Mutagenicity

Conclusion/Summary : No mutagenic effect.

Teratogenicity

Conclusion/Summary : No known significant effects or critical hazards.

Reproductive toxicity

Product / ingredient name	Maternal toxicity	Fertility	Development toxin	Species	Dose	Exposure	References
Nitric acid, calcium salt (2:1)	-	Negative	Negative	Rat	Oral: > 1500 mg/kg bw/day	-	IUCLID 5

					Repeated dose		

Conclusion/Summary : No known significant effects or critical hazards.

IDLH : No data available.

12.Ecological information

Ecotoxicity : No known significant effects or critical hazards.

Aquatic ecotoxicity

Product / ingredient name	Result	Species	Exposure	References
Nitric acid, calcium salt (2:1)				
	Acute LC50 1,378 mg/l Fresh water OECD 203	Fish - Labeo boga	96 h	IUCLID 5
	Acute LC50 2,400 mg/l Fresh water	Fish - Lepomis macrochirus	4 d	Proc. Acad. Nat. Sci. Philadelphia106: 185-205
	Acute LC50 490 mg/l Fresh water	Aquatic invertebrates.	48 h	IUCLID 5
	Acute EC50 > 1,700 mg/l Salt water	Aquatic plants - Heterosigma akashiwo	10 d	IUCLID 5

Conclusion/Summary : The product does not show any bioaccumulation phenomena. The product is not expected to harm the environment when used properly according to directions.

Persistence/degradability

Conclusion/Summary : Readily biodegradable in plants and soils.

Partition coefficient: n-octanol/water : Not available.

Mobility : This product may move with surface or groundwater flows because its water solubility is: high

Other adverse effects : No known significant effects or critical hazards.

13. Disposal considerations

Product

Methods of disposal : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed out. Empty containers or liners may retain some product residues. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Empty the bag by shaking to remove as much as possible of its contents. Empty bags may be disposed of as non-hazardous material or returned for recycling.

Disposal should be in accordance with applicable regional, national and local laws and regulations.

Refer to Section 7: HANDLING AND STORAGE and Section 8: EXPOSURE CONTROLS/PERSONAL PROTECTION for additional handling information and protection of employees.

14.Transport information

Regulation: UN Class	
14.1 UN number	Not regulated.
14.2 UN proper shipping name	
14.3 Transport hazard class(es)	
14.4 Packing group	
14.5 Environmental hazards	No.
Additional information	**: UN Class**
Environmental hazards	**:** No.

Regulation: IMDG	
14.1 UN number	Not regulated.
14.2 UN proper shipping name	
14.3 Transport hazard class(es)	
14.4 Packing group	
14.5 Environmental hazards	No.
14.6 Additional information	**: IMDG**
Marine pollutant	**:** No.

Regulation: IATA	
14.1 UN number	Not regulated.
14.2 UN proper shipping name	
14.3 Transport hazard class(es)	
14.4 Packing group	
14.5 Environmental hazards	No.
14.6 Additional information	**: IATA**
Marine pollutant	**:** No.

Regulation: DOT Classification	
14.1 UN number	Not regulated.
14.2 UN proper shipping name	
14.3 Transport hazard class(es)	
14.4 Packing group	
14.5 Environmental hazards	No.
14.6 Additional information	**: DOT Classification**
Environmental hazards	**:** No.

Regulation: TDG Class	
14.1 UN number	Not regulated.
14.2 UN proper shipping name	
14.3 Transport hazard class(es)	

14.4 Packing group	
14.5 Environmental hazards	No.
14.6 Additional information	**: TDG Class**
Environmental hazards	**:** No.

Special precautions for user : Transport within user's premises: always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.'

IMSBC : Not available.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code : Not applicable.

15.Regulatory information

United States

HCS Classification : Toxic material
Irritating material

U.S. Federal regulations :
United States - TSCA 12(b) - Chemical export notification: None of the components are listed.
United States - TSCA 4(a) - Final Test Rules: Not listed
United States - TSCA 4(e) - ITC Priority list: Not listed
United States - TSCA 4(a) - Proposed test rules: Not listed
United States - TSCA 4(f) - Priority risk review: Not listed
United States - TSCA 5(a)2 - Final significant new use rules: Not listed
United States - TSCA 5(a)2 - Proposed significant new use rules: Not listed
United States - TSCA 5(e) - Substances consent order: Not listed
United States - TSCA 6 - Final risk management: Not listed
United States - TSCA 6 - Proposed risk management: Not listed
United States - TSCA 8(a) - Comprehensive assessment report (CAIR): Not listed
United States - TSCA 8(a) - Chemical risk rules: Not listed
United States - TSCA 8(a) - Dioxin/Furane precusor: Not listed
United States - TSCA 8(a) - Chemical Data Reporting (CDR): Not determined
United States - TSCA 8(a) - Preliminary assessment report (PAIR): Not listed
United States - TSCA 8(c) - Significant adverse reaction (SAR): Not listed
United States - TSCA 8(d) - Health and safety studies: Not listed
SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: No products were found.
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: Nitric acid potassium salt: Del, Fire hazard - flammable, combustible liquid, pyrophoric Nitric acid, calcium salt

(2:1): Fire hazard - flammable, combustible liquid, pyrophoric
United States - EPA Clean water act (CWA) section 307 - Priority pollutants: Not listed
United States - EPA Clean water act (CWA) section 311 - Hazardous substances: Not listed
United States - EPA Clean air act (CAA) section 112 - Accidental release prevention - Flammable substances: Not listed
United States - EPA Clean air act (CAA) section 112 - Accidental release prevention - Toxic substances: Not listed
United States - Department of commerce - Precursor chemical: Not listed

Clean Air Act Section 112(b) Hazardous Air Pollutants (HAPs)	:	Not listed
Clean Air Act Section 602 Class I Substances	:	Not listed
Clean Air Act Section 602 Class II Substances	:	Not listed
DEA List I Chemicals (Precursor Chemicals)	:	Not listed
DEA List II Chemicals (Essential Chemicals)	:	Not listed

SARA 313

		Product name	CAS number	Concentration
Form R - Reporting requirements	:	Nitric acid, calcium salt (2:1)	10124-37-5	70 - 80
Supplier notification	:	Nitric acid, calcium salt (2:1)	10124-37-5	70 - 80

SARA 313 notifications must not be detached from the MSDS and any copying and redistribution of the MSDS shall include copying and redistribution of the notice attached to copies of the MSDS subsequently redistributed.

State regulations

Massachusetts	:	The following components are listed: Nitric acid potassium salt
New York	:	None of the components are listed.
New Jersey	:	The following components are listed: Nitric acid, calcium salt (2:1) Nitric acid potassium salt
Pennsylvania	:	The following components are listed: Nitric acid potassium salt

California Prop. 65

This product contains a chemical (or chemicals) known to the State of California to cause cancer and birth defects or other reproduc

Remark	:	To our knowledge no other country or state specific regulations are applicable.

International lists

Philippines inventory (PICCS): All components are listed or exempted.
New Zealand Inventory of Chemicals (NZIoC): All components are listed or exempted.
Korea inventory: All components are listed or exempted.
Japan inventory: All components are listed or exempted.

China inventory (IECSC): All components are listed or exempted.
Australia inventory (AICS): All components are listed or exempted.
Canada inventory: All components are listed or exempted.
Malaysia Inventory (EHS Register): Not determined.
Taiwan inventory (CSNN): Not determined.
United States inventory (TSCA 8b): All components are listed or exempted.
EC INVENTORY (EINECS/ELINCS): All components are listed or exempted.

16.Other information

Label requirements : HARMFUL IF SWALLOWED. CAUSES EYE IRRITATION.

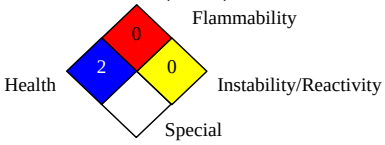
Hazardous Material Information System (U.S.A.)

Health	-	2
Flammability		0
Physical hazards		0

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks Although HMIS® ratings are not required on MSDSs under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered mark of the National Paint & Coatings Association (NPCA). HMIS® materials may be purchased exclusively from J. J. Keller (800) 327-6868. The customer is responsible for determining the PPE code for this material.

Chronic toxicity:
- : No data available.
*** :** Carcinogen, Target organs, Reproductive effects, Sensitizer to lungs

National Fire Protection Association (U.S.A.)



Reprinted with permission from NFPA 704-2001, Identification of the Hazards of Materials for Emergency Response Copyright ©1997, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.
Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Key to abbreviations :
ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
bw = Body weight
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IDLH = Immediately Dangerous to Life or Health
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL 73/78 = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
SARA = Superfund Amendments and Reauthorization Act

UN = United Nations

References	:	EU REACH IUCLID5 CSR. National Institute for Occupational Safety and Health, U.S. Dept. of Health, Education, and Welfare, Reports and Memoranda Registry of Toxic Effects of Chemical Substances. IHS, 4777 Levy Street, St Laurent, Quebec HAR 2P9, Canada.
Date of printing	:	04/05/2013
Prepared by	:	Yara Product Classifications & Regulations.
Date of issue	:	00/00/0000
Date of previous issue	:	00/00/0000
Version	:	0.0

‖ Indicates information that has changed from previously issued version.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein. Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

APPENDIX

C

SCOPE OF WORK

Knowledge grows

Proposal for Student bachelor thesis NTNU University

The objective study of this project is to find out the effect of Calcium Nitrate (CN) on hydration and strength development of (Ground Granulated Blast Slag (GGBS) blended cement in cold climate ambient.

1 Background information:

Calcium nitrate is a well-known concrete admixture used for accelerate the cement hydration of Portland cement in wide range of temperatures especially in low temperatures. However, replacing clinker based cementitious material with GGBS might be challenging to uphold mix design requirements such as concrete hydration performance and strength development in such low temperatures.
Calcium Nitrate (CN) is a common setting accelerator for many years in line with EN 934-2 table 6 or ASTM C494 type C. The effect and its performance has been evaluated in early 90s by Justnes and Nygaard (1993). CN increases soluble calcium content in the freshly mixed concrete. The calcium concentration causes earlier formation and precipitation of calcium hydroxide and accelerate formation of calcium silicate hydrate (C-S-H) by reducing initial crystallization time and eventually renewal of alite hydration. However in blended cements CN does not react directly with SCMs but indirectly by reacting with the calcium aluminate hydrate compounds formed.

2 Proposed test setup

One CEM I is blended with one type of slag to replacement level of 25% and 50%. The hydration profile of mixes of cement paste with w/c = 0.45 at temperature of 5°C with 3 levels of CN; 0, 2 and 4% as dry material bwoc. (added as 50% calcium nitrate solution provided by Yara).
For strength measurements, three sets of parallels for each of 3 mix designs is suggested. The cube dimensions of 160x40x40 mm to be made for each mixes. These cubes to be used to test compressive strength after 1, 3, 7 ad 28 days curing at 5°C. Overview of mixes are presented in table below:

		Mix Ref-1	Mix Ref-2	Mix CN-2-25	Mix CN-2-50	Mix CN-4-25	Mix CN-4-50	
		CN		CN		CN		
		0	0	2%	2%	4%	4%	
		GGBS		GGBS		GGBS		
		25%	50%	25%	50%	25%	50%	
		CEM I		CEM I		CEM I		
		75%	50%	75%	50%	75%	50%	
Compressive strength	1 day	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	18
	3 days	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	18
	7 days	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	18
	28 days	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	3 parallels	18
	Total:	12	12	12	12	12	12	72

Knowledge grows

The number of parallels can be reduced. However, three parallels would help to have more representative results. In addition, the mass of prisms (after de-molding) can indicate compaction errors or variations in air content.

Yara will provide Calcium nitrate 50% solution for the cement pastes (hydration test) and mortar paste (strength measurements).

Knowledge grows

Proposal for Student bachelor thesis NTNU University

The objective study of this project is to find out the effect of Calcium Nitrate (CN) on hydration and strength development of (Ground Granulated Blast Slag (GGBS) blended cement in cold climate ambient.

1 Background information:

Calcium nitrate is a well-known concrete admixture used for accelerate the cement hydration of Portland cement in wide range of temperatures especially in low temperatures. However, replacing clinker based cementitious material with GGBS might be challenging to uphold mix design requirements such as concrete hydration performance and strength development in such low temperatures.
Calcium Nitrate (CN) is a common setting accelerator for many years in line with EN 934-2 table 6 or ASTM C494 type C. The effect and its performance has been evaluated in early 90s by Justnes and Nygaard (1993). CN increases soluble calcium content in the freshly mixed concrete. The calcium concentration causes earlier formation and precipitation of calcium hydroxide and accelerate formation of calcium silicate hydrate (C-S-H) by reducing initial crystallization time and eventually renewal of alite hydration. However in blended cements CN does not react directly with SCMs but indirectly by reacting with the calcium aluminate hydrate compounds formed.

2 Proposed test setup

One CEM I is blended with one type of slag to replacement level of 50%. The hydration profile of mixes of cement paste with w/c = 0.45 at temperature of 5°C with 3 levels of CN; 0, 2 and 4% as dry material bwoc. (added as 50% calcium nitrate solution provided by Yara).
For strength measurements, two sets of parallels for each of 3 mix designs is suggested. The cube dimensions of 160x40x40 mm to be made for each mixes. These cubes to be used to test compressive strength after 1, 3, 7 ad 28 days curing at 5°C. Overview of mixes are presented in table below:

Knowledge grows

		Mix Ref-1	Mix CN-2-50	Mix CN-4-50	
		CN	CN	CN	
		0	2%	4%	
		GGBS	GGBS	GGBS	
		50%	50%	50%	
		CEM 1	CEM 1	CEM 1	
		50%	50%	50%	
Compressive strength	1 day	2 parallels	2 parallels	2 parallels	6
	3 days	2 parallels	2 parallels	2 parallels	6
	7 days	2 parallels	2 parallels	2 parallels	6
	28 days	2 parallels	2 parallels	2 parallels	6
	Total:	8	8	8	24

Yara will provide Calcium nitrate 50% solution for the cement pastes (hydration test) and mortar paste (strength measurements). NTNU will provide CEM1 for and Sintef will provide GGBS.

APPENDIX

D

ATTACHMENTS

D.0.1 Terms of Agreement

NTNU
Norwegian University of Science and Technology

Approved by the Pro-Rector for Education 10 December 2020

STANDARD AGREEMENT

on student works carried out in cooperation with an external organization

The agreement is mandatory for student works such as master's thesis, bachelor's thesis or project assignment (hereinafter referred to as works) at NTNU that are carried out in cooperation with an external organization.

Explanation of terms

Copyright
Is the right of the creator of a literary, scientific or artistic work to produce copies of the work and make it available to the public. A student thesis or paper is such a work.

Ownership of results
Means that whoever owns the results decides on these. The basic principle is that the student owns the results from their own student work. Students can also transfer their ownership to the external organization.

Right to use results
The owner of the results can give others a right to use the results – for example, the student gives NTNU and the external organization the right to use the results from the student work in their activities.

Project background
What the parties to the agreement bring with them into the project, that is what each party already owns or has rights to and which is used in the further development of the student's work. This may also be material to which third parties (who are not parties to the agreement) have rights.

Delayed publication (embargo)
Means that a work will not be available to the public until a certain period has passed; for example, publication will be delayed for three years. In this case, only the supervisor at NTNU, the examiners and the external organization will have access to the student work for the first three years after the student work has been submitted.

1. Contracting parties

The Norwegian University of Science and Technology (NTNU) Department: Department of Structural Engineering
Supervisor at NTNU: Arne Mathias Selberg email and telephone: arne.m.selberg@ntnu.no +47 734 12 049
External organization: Yara Contact person, email address and telephone number of the external organization: Mehrdad Torabzadegan, mehrdad.torabzadegan@yara.com, +47 927 71 646
Student: Aleksandra Marie Høye Date of birth: 28.05.1999
Other students, if applicable[1] Elise Marie Rong Anfinsen 18.10.1998
Margrethe Munch-Ellingsen 02.01.1998

The parties are responsible for clearing any intellectual property rights that the student, NTNU, the external organization or third party (which is not a party to the agreement) has to project background before use in connection with completion of the work. Ownership of project background must be set out in a separate annex to the agreement where this may be significant for the completion of the student work.

2. Execution of the work

The student is to complete: (Place an X)

A master's thesis	
A bachelor's thesis	x
A project assignment	
Another student work	

Start date: 01.01.23
Completion date: 17.05.23

[1] If several students co-author a work, they can all be listed here. The students then have joint rights to the work. If an external organization instead wants a separate agreement to be concluded with each student, this is done.

The working title of the work is: Experimental study of calcium nitrate induced concrete to enhance cement hydration performance

The responsible supervisor at NTNU has the overarching academic responsibility for the design and approval of the project description and the student's learning.

3. Duties of the external organization

The external organization must provide a contact person who has the necessary expertise to provide the student with adequate guidance in collaboration with the supervisor at NTNU. The external contact person is specified in Section 1.

The purpose of the work is to carry out a student assignment. The work is performed as part of the programme of study. The student must not receive a salary or similar remuneration from the external organization for the student work. Expenses related to carrying out the work must be covered by the external organization. Examples of relevant expenses include travel, materials for building prototypes, purchasing of samples, tests in a laboratory, chemicals. The student must obtain clearance for coverage of expenses with the external organization in advance.

The external organization must cover the following expenses for carrying out the work: Yara will provide Calcium Nitrate (CN) needed for the casting cement paste or mortars according to proposal of scope of work. SINTEF (contact person: Prof. Harald Justnes) will provide GGBS as needed. NTNU will provide CEM 1. If other material is needed, students or NTNU will place the order. Costs can be covered by Yara.

Coverage of expenses for purposes other than those listed here is to be decided by the external organization during the work process.

4. The student's rights

Students hold the copyright to their works [2]. All results of the work, created by the student alone through their own efforts, is owned by the student with the limitations that follow from sections 5, 6 and 7 below. The right of ownership to the results is to be transferred to

[2] See Section 1 of the Norwegian Copyright Act of 15 June 2018 [Lov om opphavsrett til åndsverk]

the external organization if Section 5 b is checked or in cases as specified in Section 6 (transfer in connection with patentable inventions).

In accordance with the Copyright Act, students always retain the moral rights to their own literary, scientific or artistic work, that is, the right to claim authorship (the right of attribution) and the right to object to any distortion or modification of a work (the right of integrity).

A student has the right to enter into a separate agreement with NTNU on publication of their work in NTNU's institutional repository on the Internet (NTNU Open). The student also has the right to publish the work or parts of it in other connections if no restrictions on the right to publish have been agreed on in this agreement; see Section 8.

5. Rights of the external organization

Where the work is based on or further develops materials and/or methods (project background) owned by the external organization, the project background is still owned by the external organization. If the student is to use results that include the external organization's project background, a prerequisite for this is that a separate agreement on this has been entered into between the student and the external organization.

Alternative a) (Place an X) General rule

X	The external organization is to have the right to use the results of the work

This means that the external organization must have the right to use the results of the work in its own activities. The right is non-exclusive.

Alternative B) (Place an X) Exception

	The external organization is to have the right of ownership to the results of the task and the student's contribution to the external organization's project

Justification of the external organization's need to have ownership of the results transferred to it:

6. Remuneration for patentable inventions

If the student, in connection with carrying out the work, has achieved a patentable invention, either alone or together with others, the external organization can claim transfer of the right to the invention to itself. A prerequisite for this is that exploitation of the invention falls within the external organization's sphere of activity. If so, the student is

entitled to reasonable remuneration. The remuneration is to be determined in accordance with Section 7 of the Employees' Inventions Act. The provisions on deadlines in Section 7 apply correspondingly.

7. NTNU's rights

The submitted files of the work, together with appendices, which are necessary for assessment and archival at NTNU belong to NTNU. NTNU receives a right, free of charge, to use the results of the work, including appendices to this, and can use them for teaching and research purposes with any restrictions as set out in Section 8.

8. Delayed publication (embargo)

The general rule is that student works must be available to the public.

Place an X

X	The work is to be available to the public.

In special cases, the parties may agree that all or part of the work will be subject to delayed publication for a maximum of three years. If the work is exempted from publication, it will only be available to the student, external organization and supervisor during this period. The assessment committee will have access to the work in connection with assessment. The student, supervisor and examiners have a duty of confidentiality regarding content that is exempt from publication.

The work is to be subject to delayed publication for (place an X if this applies):

Place an X		Specify date
	one year	
	two years	
	three years	

The need for delayed publication is justified on the following basis:

If, after the work is complete, the parties agree that delayed publication is not necessary, this can be changed. If so, this must be agreed in writing.

Appendices to the student work can be exempted for more than three years at the request of the external organization. NTNU (through the department) and the student must accept this if the external organization has objective grounds for requesting that one or more

appendices be exempted. The external organization must send the request before the work is delivered.

The parts of the work that are not subject to delayed publication can be published in NTNU's institutional repository – see the last paragraph of Section 4. Even if the work is subject to delayed publication, the external organization must establish a basis for the student to use all or part of the work in connection with job applications as well as continuation in a master's or doctoral thesis.

9. *General provisions*

This agreement takes precedence over any other agreement(s) that have been or will be entered into by two of the parties mentioned above. If the student and the external organization are to enter into a confidentiality agreement regarding information of which the student becomes aware through the external organization, NTNU's standard template for confidentiality agreements can be used.

The external organization's own confidentiality agreement, or any confidentiality agreement that the external party has entered into in collaborative projects, can also be used provided that it does not include points in conflict with this agreement (on rights, publication, etc). However, if it emerges that there is a conflict, NTNU's standard contract on carrying out a student work must take precedence. Any agreement on confidentiality must be attached to this agreement.

Should there be any dispute relating to this agreement, efforts must be made to resolve this by negotiations. If this does not lead to a solution, the parties agree to resolution of the dispute by arbitration in accordance with Norwegian law. Any such dispute is to be decided by the chief judge (sorenskriver) at the Sør-Trøndelag District Court or whoever he/she appoints.

This agreement is signed in four copies, where each party to this agreement is to keep one copy. The agreement comes into effect when it has been signed by NTNU, represented by the Head of Department.

Signatures:

Head of Department: Date:
Supervisor at NTNU: Date: 27.02.2023
External organization: Date: 21.02.2023 Mohrdad Torabzadegan
Student: Aleksandra M. Høye Date: 17.02.2023

Other students, if applicable: Elise Marie Rong Anfinsen Date: 17.02.2023
Margrethe Munch-Ellingsen Date: 17.02.2023

D.0.2 Equipment List

Equipment List for Moulding of Concrete Cubes, as well as Compressive Strength Testing……

While measuring:

1. Pipet
2. Measuring cups, 200ml – 2000 ml
3. Scale
4. Trowel, masons' trowel, small spoon
5. Brush
6. Metal bowls
7. Plastic buckets

Materials:

1. Norcem Anlegg. CEM I, 52,5N
2. NitCal
3. GGBS
4. Elkem Microsilica
5. Water
6. Årdal 0/8 mm sand
7. Årdal 8/16 mm gravel (stein)
8. Mapei Dynamon SX – 23

Moulding:

1. Cube shaped steel moulds, 100x100x100 mm
2. Separol W220
3. Squared and oval masons' trowel
4. Concrete shovel
5. Rodding stick
6. Mallet
7. Grout spoon
8. Aluminium flat bar
9. PMat Zyklos 50L Concrete tumbler
10. Water hose

When conducting quality testing:

1. FLUKE 63 IR Thermometer
2. FTSB2020
3. Spray bottle
4. Metal container. Weight: 4705,2 kg; v = 7 982,77 cm^3
5. Paper towels
6. Slump cone
7. Thumb stick

Soft, - and hardware:

1. Toni TROL II, Model 0560
2. Test Xpert iii – v1.7
3. Computer
4. CatMan AP 5.5.2