Use of alternative ashes in concrete - Workability and hardening



Figure 1: Test specimens with 5 % cement (bottom) and 10 % sand (top) replacement

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04.06.2014



1 Preface

This report is written as a bachelor project with Department of Civil Engineering at Technical University of Denmark. The report constitutes 15 ECTS points and has a target audience of third year students at DTU and other technical universities.

Besides being a two man group, we have been part of a project family consisting of five groups. Each group was given a specific ash for it to examine. During the preliminary part, all groups conducted the same tests on their own ash, to characterise it. After two months of preliminary tests, the results were presented in a poster presentation. After this presentation each group went their seperate ways in terms of investigation subjects.

The project supervisors are Lisbeth M. Ottosen, Per Goltermann and Pernille Erland Jensen. Furthermore, Ebba Cederberg Schnell, Sabrina Madsen and Per Leth have provided valuable assistance throughout the project. At last we credit Lynettefællesskabet I/S for delivering the subjected sludge ash.

The subjected sludge ash has been extracted directly from the furnace, meaning that it has not been stored for a longer period of time.



TECHNICAL UNIVERSITY OF DENMARK Kongens Lyngby, 4th of June 2014

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2 Abstract

The present paper mainly examines the impact of phosphate (PO_4^{3-}) on the early age compressive strength of cement mortar. In relation to use of sludge ash in concrete, it has great relevance to establish a threshold value for the phosphate content in the ash, in order to avoid unexpected failure of the mortar. The project consists of a preliminary part and a further part. In the preliminary part, the basics of the given sludge ash from Lynettefællesskabet I/S are determined with a thorough ash characteristic. Furthermore, compressive strength tests and testing of setting time were conducted on a reference mortar, containing no sludge ash, a 5 % cement mortar, where 5 % of the cement were replaced with ash and a 10 % sand replacement, where 10 % of the sand were replaced with ash.

The initial tests of the setting times were conducted with a Vicatronic-apparatus on the same mortars as used for the compressive strength and showed, that the setting time became slower the more ash was added to the mortar. This meant that the reference mortar had the fastest setting time of 250 minutes, followed by the 5 % cement replacement mortar with a setting time of 260 minutes and at last the 10 % sand replacement mortar with a time of 350 minutes.

The initial tests formed the foundation of deciding the subject of the further part. It was found, that the ash contained 9.38 % of phosphate and that the compressive strength lowered concurrently with addition of sludge ash. These results delimited the subject for the further part: Determination of the effect of phosphate on the compressive strength of cement mortar in the early age (1-5 days).

For the further part it was chosen to proceed with the 5 % cement replacement mortar in spite of the fact, that after the initial strength tests, the 5 % cement replacement mortar and the reference mortar had a relative deviation of 19.2 % after 5 days. Because the 5 % cement replacement mortar still had a strength of 38.5 MPa compared to the reference mortar's of 45.9 MPa and the 10 % sand replacement mortar's of 43.1 MPa, it was reasoned, that the 5 % cement replacement mortar had the most relevance in terms of economical and environmental savings, and was therefore chosen for further subjection.

The further testing consisted of mixing solutions with different concentrations of a readily soluble phosphate salt into the mortar mix to substitute the pure water. For the solutions, ammonium dihydrogen phosphate $(NH_4H_2PO_4)$ was used, as a result of its solubility. The solution was initially made in concentrations of 0.10 M, 1.00 M and 3.25 M (saturated) in order to narrow down a threshold value for the phophate content. The 3.25 M solution turned out be impossible to handle, which gave the 1.00 M status as the upper limit for the examined range and a 0.50 M solution was made instead.

After testing the compressive strength of the reference mortar and 5 % cement replacement mortar with concentrations of 0.10 M, 0.50 M and 1.00 M $NH_4H_2PO_4$ and with just demineralised water (DM water), the 0.50 M solution was named as the new upper limit, because the mortar with 1.00 M solution for the reference had a strength of 24.1 MPa after 5 days, compared to the strengths of the mortars with DM water, 0.10 M and 0.50 M of 45.9 MPa, 47.3 MPa and 32.5 MPa respectively. It was noted, that the strength of the 0.10 M mortar was slightly higher than of the mortar with DM water, but this property of the 0.10 M mortar was not recognised and the two strengths were accounted as being alike.

The same tendency was present for the 5 % cement replacement mortar, where the 1.00 M mortar had a strength of 20.6 MPa and the 0.10 M and 0.50 M mortars had strengths of respectively 41.0 MPa and 32.7 MPa after 5 days. Accordingly, a new solution with a concentration of 0.25 M was made.

For the reference mortar the 0.25 M solution turned out to delimit the range of phosphate content together with the 0.10 M solution, due to the fact that the 0.25 M mortar had a visibly lower strength (compared to 0.10 M) of 43.0 MPa after 5 days. This however was not the case for the 5 % replacement mortar,

where the strength of the 0.25 M mortar turned out to be 39.1 MPa after 5 days, which made the 0.50 M the upper limit of the range, because the strength of the 0.25 M was almost as high as for the 0.10 M.

As for the compressive strength test, the setting time was examined for a reference and a 5 % cement replacement mortar with $NH_4H_2PO_4$ solutions. The setting of the 1.00 M mortars for both the reference and 5 % cement replacement happened within the first 7 minutes. For the reference mortar, the 0.10 M set after 400 minutes, the 0.25 M set after 410 minutes and the 0.50 M set after 550 minutes. For the 5 % cement mortar, the 0.10 M set after 300 minutes, the 0.25 M after 420 minutes and the 0.50 M set after 450 minutes.

The conclusion to be drawn from this paper is, that the added ash to the 5 % cement replacement mortar does not contain enough free phosphate to have an effect on the compressive strength. This is due to the fact, that the actual concentration of phosphate from 5 % sludge ash (22.5 g) is 0.06 $\frac{\text{mol}}{\text{L}}$ where the lower limit found was 0.10 $\frac{\text{mol}}{\text{L}}$. As an extra safety factor, the lower limit of 0.10 $\frac{\text{mol}}{\text{L}}$ did not have an effect on the strength either since it shows the same strength as the mortar mixed with DM water. The actual concentration can thereby be said to be safe. Not all of the phosphate in the sludge ash is soluble and thereby liberated in an alkaline solution, so the actual content is represented by the amount of the phosphate, which is base soluble and not acid soluble.

3 Abstract (Danish)

Denne rapport undersøger primært påvirkningen af fosfat (PO_4^{3-}) på trykstyrken af mørtelblandinger i den tidlige fase. I forbindelse med at anvende slamaske i beton, har det stor relevans at kunne bestemme en grænseværdi for indholdet af fosfat i asken for at undgå uforudsete fejl i mørtlen. Projektet består af en indledende fase og en videre fase. I den indledende fase er basisforholdende for en slamaske fra Lynettefællesskabet I/S bestemt ved en grundig askekarakteristik. Derudover blev der udført forsøg der skulle afdække trykstyrken samt afbindingstiden for hhv. en referenceblanding (intet tilsat slamaske), en 5 % cementerstatning (5 % af cementen blev erstattet af slamaske) og en 10 % sanderstatning (10 % af sandet blev erstattet af slamaske).

De indledende forsøg til bestemmelse af afbindingstiden blev udført med et Vicatronic-apparat på de samme mørtelblandinger som blev brugt til trykstyrkeforsøgene. Resultaterne viste at afbindingstiden blev langsommere jo mere aske der blev tilsat mørtelblandingen. Det betød at referenceblandingen havde den hurtigste afbindingstid på 250 minutter efterfulgt af 5 % cementerstatningen med en afbindingstid på 260 minutter. Den længste afbindingstid var for 10 % sanderstatning og var på 350 minutter.

Fundamentet for projektarbejdet i den videre fase blev udgjort af resultaterne fra de indledende forsøg som viste at slamasken indeholdte 9,38 % fosfat, samtidig med at trykstyrken blev mindre i takt med en forøget tilsætning af slamaske til mørtelblandingen. Disse resultater afgrænsede emnet for den videre fase: Bestemmelse af effekten af fosfat på trykstyrken i den tidlige fase (1-5 døgn).

I den videre fase blev det besluttet af fortsætte undersøgelsen af 5 % cementerstatning selvom de indledende trykstyrketests viste en relativ variation på 19,2 % i forhold til referenceblandingen efter 5 døgn. 5 % cementerstatningen havde dog imidlertid en styrke på 38,5 MPa i forhold til referenceblandingens på 45,9 MPa og 43,1 MPa for 10 % sanderstatning, og det blev derfor besluttet at arbejde videre med 5 % cementerstatning grundet det største potentiale med hensyn til økonomisk og miljømæssig gevinst.

Den videre fase bestod i at blande opløsninger med forskellige koncentrationer af et letopløseligt fosfat-salt i mørtelblandingen og derved substituere vandet. Til opløsningerne blev ammonium dihydrogen fosfat (NH₄H₂PO₄) anvendt grundet dets opløselighed. Opløsningerne blev først lavet med koncentrationer på 0,10 M, 1,00 M og 3,25 M (mættet) for at kunne bestemme en grænseværdi for indholdet af fosfat. Det viste sig at være umuligt at anvende opløsningen på 3,25 M som derved gjorde 1,00 M-opløsningen til den øvre grænse for testområdet. En 0,50 M opløsning blev lavet i stedet.

Efter at have testet trykstyrken for både referenceblandingen og 5 % cementerstatningen for koncentrationer af 0,10 M, 0,50 M og 1,00 M $\rm NH_4H_2PO_4$ og kun demineraliseret vand (DM vand), blev 0,50 M den nye øvre grænse. Dette skyldtes at mørtlen med 1,00 M opløsningen for referenceblandingen havde en styrke på 24,1 MPa efter 5 døgn sammenlignet med styrkerne for DM vand, 0,10 M og 0,50 M på hhv. 45,9 MPa, 47,3 MPa og 32,5 MPa. Det viste sig at styrken for 0,10 M mørtlen var en anelse højere end blandingen med DM vand, men de blev dog betragtet som værende af samme styrke.

Samme tendens viste sig for 5 % cementerstatningen hvor 1,00 M blandingen havde en trykstyrke på 20,6 MPa og 0,10 M og 0,50 M havde styrker på hhv. 41,0 MPa og 32,7 MPa efter 5 døgn. Herefter blev en ny opløsning med en koncentration på 0,25 M lavet.

For referenceblandingen viste opløsningen på 0,25 M sig, sammen med 0,10 M-opløsningen, at afgrænse intervallet for indholdet af fosfat da 0,25 M havde en synligt lavere styrke (sammenlignet med 0,10 M) på 43,0 MPa efter 5 døgn. Det samme var ikke gældende for 5 % cementerstatningen hvor styrken for 0,25 M viste sig at være 39,1 MPa efter 5 døgn. Dette gjorde opløsningen på 0,50 M til den øvre grænse da styrken for 0,25 M næsten var ligeså høj som for 0,10 M.

Som for trykstyrkeforsøgene blev der udført forsøg for afbindingstiden med en referenceblanding og en 5 % cementerstatning med NH₄H₂PO₄-opløsninger. Afbindingen af 1,00 M blandingen skete inden for de første 7 minutter for både referenceblandingen og 5 % cementerstatningen, hvilket højst sandsynligt skyldtes udtørring af cementpastaen og ikke afbinding. For referenceblandingen var afbindingstiden 400, 410 og 550 minutter for hhv. 0,10 M, 0,25 M og 0,50 M. For 5 % cementerstatningen var afbindingstiden 300, 420 og 450 minutter for hhv. 0,10 M, 0,25 M og 0,50 M.

Konklusionen der kan drages af denne rapport er at den mængde slamaske der bliver tilføjet til 5 % cementerstatningen ikke indeholder nok frit fosfat til at have en indvirkning på trykstyrken inden for de første 5 døgn. Dette skyldes at den faktiske koncentration af de tilsatte 5 % slamaske (22,5 g) giver en koncetration på 0,06 $\frac{\text{mol}}{\text{L}}$ hvor den nedre grænse for mængden af fosfat der kan tilsættes er fundet til 0,10 $\frac{\text{mol}}{\text{L}}$. Som en ekstra sikkerhedsfaktor har grænsen på 0,10 $\frac{\text{mol}}{\text{L}}$ heller ingen effekt på trykstyrken da forsøgene viser samme styrke som med DM vand. Koncentrationen af fosfat i slamasken har derfor ingen signifikant betydning for trykstyrkeudviklingen inden for de første 5 døgn. Ikke alt fosfatet i asken er opløseligt og derved frigjort i en basisk opløsning, dvs. at det faktiske indhold i slamasken repræsenteres af den mængde fosfat der er baseopløseligt og ikke syreopløseligt.

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4 Introduction

This project is a continuation of previous tests and projects concerning alternative aggregates and cement replacement in concrete. It is also a part of the ZeroWaste-programme at Department of Civil Engineering, DTU, which investigates the use of waste products such as fly ash and, as in this case, sludge ash in concrete structures.

Due to an initial characterisation of the ash, showing an amount of phosphate of 9.38 %, it has been chosen to use this high concentration to mark off the extend of the project.

A great deal of the interest in re-use of waste products lies within the savings of not having to deposit potentially environmentally damaging sludge ash. Wastewater treatment plants pay a deposit fee of around 600 DKK per tonne of ash [37], which would be saved, if they could merely give it away for alternative use, e.g. in the construction industry. Accordingly, it is interresting to examine the replacement of cement with sludge ash. This however comes with certain concerns about e.g. leaching of heavy metals and harmful macros. The environmental impression of sludge ash is not all bad though. The phosphate within the ash turns out to be valuable to the agricultural trade, since the natural reserves of phosphate to be mined will run out at some point [4]. Another consideration is the price of cement of about 2.3 $\frac{DKK}{kg}$, whereas the price for comparison of sand is about 0.8 $\frac{DKK}{kg}$, which is approx a third of the price of cement. In short terms, treatment and re-use of sludge ash proves as a source of income within multiple industries.

The effect of phosphate on the compression strength will be studied due to lack of knowledge on this specific area. Another target of the delimitation is to narrow down a threshold value of phosphate concentration in the ash used in concrete, with respect to the compressive strength. To test the effect of phosphate, different concentrations of the readily soluble salt, ammonium dihydrogen phosphate $(NH_4H_2PO_4)$, is added to the mortar to substitute pure water.

As mentioned, this report is a continuation of the work of previous students. On this behalf the sludge ash has been milled without further testing, due to conclusions in the report of Morten Reiff and Morten G. Meldgaard [40]. The milling of the ash has been conducted cf. the official FRITSCH operating manual for the Pulverisette 9 vibrating cup mill [12].

The following words have been used at the DTU Findit portal in search of previous work concerning the effect of phosphate on compressive strength of concrete: "phosphate+concrete+sludge+ash". This search presented a journal written by Shane Donatello and Christopher R. Cheeseman concerning the use of sludge ash in the Portland cement production process. The journal states, that an increase in P_2O_5 increases the content of belite (C_2S) at the expense of alite (C_3S), causing the concrete to have longer setting time and lower strength development [4]. This however is not the exact same issue as the one of this report, which subjects the use of sludge ash as an admixture itself, and not as a part of the cement production. Besides the mentioned journal, the result of the litterature study was rather limited, as there was nothing concerning the issue at hand.

It should be clear to the reader, that the purpose of this report is to clarify the possible consequences of a large amount of phosphate and not to test the phosphate as an additive to the concrete. Due to the lack of results on the litterature study, it should be recognised that this report is the first to present the effect of phosphate on the compressive strength of cement mortar in the early phase (1-5 days).

5 Theory

5.1 Concrete

Concrete is a mix product used in structures to withstand large loads, requiring compressive strengths of up to 200 MPa (high performance concrete > 50 MPa [20]) [30]. On the other hand, concrete has a very poor tensile strength, which as a rule of thumb is about 1/10 of the compressive strength for concrete in the 0-50 MPa range [45]. To compensate for the concrete's tensile weakness, roundbars of steel are cast into the stuctural component to reinforce it.

An orginal concrete mix consists of cement, water, gravel and stones. Other admixtures are added either to replace parts of the original mix or to control the properties of the concrete in terms of workability, hardening and strength development. These admixtures are cursorily presented in section 5.1.1.2.

5.1.1 Composition and properties

5.1.1.1 Cement and hydration

When water is added to the cement, the two constituents engage in a chemical reaction, starting the hydration process. During the cement production, four main cement clinker minerals are formed: C_3S , C_2S , C_3A and C_4AF . These minerals are anhydrates forming a new mineral called hydrate, when introduced to water. Figure 2 shows the strength properties of the clinker minerals, i.e. the strength development over time.



Figure 2: Strength development of cement clinker [8]

As seen from Figure 2, C_3S contributes greatly to the early age strength of the concrete where C_2S contributes to the long term strength. C_3A and C_4AF deliver no appreciable contribution to the mechanical

properties of the concrete.

The main solids formed during the hydration process are calciumsilicate hydrate (C-S-H), portlandite (CH), ettringite and monosulfate. Below in Figure 3 the four solids are shown.



Figure 3: C-S-H gel (3a), ettringite and portlandite (3b) and monosulfate (3c)

As seen in Figure 3a the C-S-H gel has kind of a spongy appearance compared to the other three clinker minerals. Figure 3b clearly shows the the spiky structure of ettringite along with the welldefined flaky structure of calcium hydroxide (CH). Figure 3c shows the hexagonal flakes of monosulphate. The combination of the minerals shown in Figure 3 is what binds the aggregates in the concrete mix together. Figure 4 is a flowchart illustrating the constituents and phases of concrete.



Figure 4: Constituents and phases of concrete (Modified after [34])

5.1.1.2 Mineral and chemical admixtures

Concrete mixtures can contain a series of mineral and chemical admixtures, e.g. retarders and plasticisers. The main purpose of the mineral admixtures is to replace cement to a somewhat limited extend, in order to reduce the environmental hasards in terms of greenhouse gas emission during cement production. The chemical admixtures are used to overcome the practical difficulties of concrete casting, e.g. by increasing the workability, accelerating or slowing down the hardening process and developing early age strength in the concrete. Below is given a list of the various chemical admixtures and their function:

- Air-entraining admixtures: Creates small air-bubbles that last in the hardened concrete to work as a pressure neutraliser when considering freeze-thaw exposures. The air content is raised from the natural content of 1-2 vol% to 5-6 vol% [22].
- Water-reducing and set-controlling admixtures: Help maintain a certain workability of concrete with a low w/c-ratio resulting in high strength. Help obtain a homogeneous mix, due to decrease of aggregate segregation [22].
- Retarding admixtures: Slows down the initial hydration of the cement. Used in hot-weather casting, since the setting time of concrete drops from 10 to 2 hours when there is a rise in temperature from 10 °C to 40 °C. Increases on-site workability [22].
- Accelerating admixtures: Used in repair work, where short setting time (within minutes) is desired. Mostly used in winter casting of concrete since it increases the heat and strength development to counterbalance the low temperature, that in a worst case scenario can stop the strength development in the early hydration process [22].
- Shrinkage-reducing admixtures: The shrinkage-reducing admixture reduces the surface tension of the free water within the capillary pores. The reduced surface tension prevents the concrete from shrinking as a result of the free water drying out [22].
- Alkali-aggregate reaction-controlling admixtures: The chemical admixture that is alkaliaggregate reaction-controlling, converts the water adsorptive gel, produced from reactions between alkali ions and SiO₂-compounds, to a non-adsorptive gel. This prevents expansion of the gel and cracks in the concrete [22].

It is known to replace a part of the cement with fly ash or silica fume as mineral admixtures because they improve the performance of the concrete [22]. With respect to strength it is reckoned that 3 kg of fly ash can substitute 1 kg of cement whereas only 2 kg of fly ash can replace 1 kg of cement when durability is taken into account [20]. Another mineral admixture is sludge ash, which compared to fly ash is a slight novelty within the construction industry. When various substances have been removed at wastewater plants the incinerated sludge (sludge ash) can be used as an admixture to replace a part of the cement, when dealing with low strength concrete as the sludge ash increases the packing of the mortar but not the pozzolanic activity [11]. The processing and properties of the sludge ash is described more in depth in section 5.2.

5.1.1.3 w/c-ratio

One of the important factors of mixdesign is having the right w/c-ratio with respect to the wanted strength. The wanted strength is determined from the purpose of the structure. The chemically bound water constitutes approx 40 % of the cement weight, which yields a theoretically optimal w/c-ratio of about 0.4 [20]. At this condition, the water and cement ideally react completely and there will be no excess water for evaporation. A typical value for this w/c-ratio, in terms of compressive strength, is in the range 40-55 MPa [34].

Excess water due to an incomplete hydration has significant influence on the strength and durability of the concrete. If the w/c-ratio is too high, the excess water will evaporate within the concrete, leaving voids of air. This gives the concrete a lower strength and makes it more porous which increases the risk

of e.g. frost damage. A w/c-ratio of 0.8 is said to be high and typically gives a compressive strength in the range 15-25 MPa [34]. The w/c-ratio is calculated from Bolomey's formula (1).

$$f_{c28} = K \cdot \left(\frac{1}{w/c} - \alpha\right) \Longrightarrow w/c = \frac{1}{\left(\frac{f_{c28}}{K} + \alpha\right)} \tag{1}$$

where f_{c28} [MPa] is the design strength, i.e. the expected strength after 28 days, and K is set to 22 for cement of strength class 42.5 MPa and 24 for high strength cement of class 52.5 MPa. α is a constant of value 0.5 for basic Portland cement with a due date of 28 days [38].

5.1.2 Setting and hardening

The first hours after the mixing process of concrete, the cement paste has liquid properties, whereafter it will harden. This is called, that the cement paste is setting. Below in Figure 5 the three phases of the structural development of cement paste are shown. The figure also shows correlation between porosity and formation of hydration products.



Figure 5: Three phases of cement paste development: Rest, setting and hardening [34]

The top part of Figure 5 shows, how the porosity decreases concurrently with the formation of hydration product. As mentioned, there are four main products of the hydration of cement. C-S-H-gel formed by C_3S and C_2S , portlandite (or calcium hydroxide) also formed by C_3S and C_2S and ettringite and monosulphate both formed by C_3A . The last product shown in Figure 5 is $C_4(A,F)H_{13}$, which is the hydration product of C_4AF .

The lower part of Figure 5 shows the three phases of the structural development of the cement paste. The first phase is rest, up until approx an hour after mixing. Then comes the second phase, where the paste sets, i.e. the formation of hydration product begins properly. This phase is current the first 10-15 hours, and is where the mortar becomes unworkable and starts to stiffen. The last phase is the hardening, where the air inside the mortar is replaced by hydration product which connects the particles into a homogeneous mass. The last phase takes over after the setting and theoretically continues until the hydration of cement is complete. It is in this phase, that the concrete develops its strength.

5.1.3 Strength development

The maturity of concrete, i.e. the equivalent hardening age at 20 °C, can be calculated from (2).

$$M_{20} = \sum f_{20}(N_i) \cdot t_i \tag{2}$$

where

$$f_{20}(N) = e^{4029 \cdot (\frac{1}{293} - \frac{1}{N+273})} \quad for \ N \ge \ 20 \,^{\circ}\text{C}$$

or

$$f_{20}(N) = e^{4029 + 177 \cdot (20 - N) \cdot (\frac{1}{293} - \frac{1}{N + 273})} \quad for \ N < \ 20^{\circ}C$$

and N_i and t_i are the temperature and length (days), respectively, of the i^{th} period [21].

Due to temperature change during the hardening period as a result of changes in weather and the fact that hydration of cement liberates heat, the hardening period can be split up into several intervals, as (2) indicates. This results in a maturity age of the concrete as a function of the variable temperature. Since the hydration process is accelerated at higher temperatures, it is desirable to know the maturity age of the concrete at a given time, as a concrete subjected to a higher temperature can be as far in the hardening process after e.g. 30 days, as a concrete at $20 \,^{\circ}$ C after e.g. 40 days.

When choosing strength class for concrete, it is actually the strength typically after 28 days of hardening that is chosen. In practice though, the concrete increases its strength throughout its service life. After the first week, the concrete has obtained approx 70 % of the 28 day strength, but even after the 28 days, the strength grows due to incomplete hydration of cement. The hydration can continue, however extremely slowly, for several years, but the continuation of strength development cannot be used as a validation factor of a structural component [20].

5.2 Sludge ash

5.2.1 Wastewater treatment

Sludge ash is the final product of wastewater treatment. The following section is a description of the wastewater treatment procedure at Lynettefællesskabet I/S.

When the wastewater enters the treatment plant a number of chemical substances are added, such as iron in the form of iron chloride (Fe(III)Cl) or aluminium in the form of aluminium chloride (AlCl). These metals will react with the phosphate in the water and form a poorly soluble substance that will precipitate and stick to the rest of the sludge. This way the phosphate is extracted in the slurry from the water [46].

When the wastewater has been treated, a large part of the sludge is reused to decompose organic material from incoming wastewater, whereas the rest is led to digesters, where the sludge disintegrates prior to incineration. The sludge is incinerated in a fluid bed furnace at around 900 °C. The "fluid" in "fluid bed" is not actually a fluid, but an air induced sand layer which the sludge is led onto. The sand seperates the sludge into tiny particles resulting in an instant combustion [24]. After incineration, some of the ash is deposited and some is utilised in other correlations, e.g. in the construction industry [19].

5.2.2 Color

The color of the sludge ash left from treating wastewater depends on which metal is used to extract the phosphate. When using iron chloride (Fe(III)Cl) [46] the ash gets a red-brownish color, as seen in Figure 6 because of the iron.



(a) Original sludge ash

(b) Milled sludge ash

Figure 6: Sludge ash directly from Lynettefællesskabet I/S (6a) along with milled sludge ash (6b)

A way to avoid the red color is to use alumiunium chloride AlCl, which gives the ash a yellow-brownish color [26].

5.2.3 Milling of the ash

According to the report of Morten Reiff and Morten G. Meldgaard the ash delivered from Lynettefællesskabet I/S has to be milled to obtain the optimal hardening and compressive strength [40].

Figure 6 shows both the ash directly from the wastewater plant along with the same ash after being milled. Offhand it is not particularly visible from the Figure 6, that the original version of the ash is more coarse than the milled version. This however can be explained by the fact, that the milled ash has a much bigger surface area, resulting in the microscopic particles to stick together. The original ash on the other hand is much more sand-like in the sense, that the individual particle is individually movable.

5.2.4 Use in concrete

When used in concrete, the sludge ash acts as any other pozzolan aggregate [26]. A pozzolan is a material that, combined with a calcium hydroxide-solution (CaOH), shows the same properties as cement in terms of hydration [22]. The calcium hydroxide comes from the reaction between a calcium silicate and water, which combined produces C-S-H-gel along with calcium hydroxide (CH, portlandite) [22]. There is not unanimity as to whether the ash acts as a pozzolan though. The sludge ash is also said to have a packing effect on the mortar, due to its fineness. When using ash that does not act as a pozzolan, the density

increases caused by suppression of air within the mortar. There is no clear answer to the question of pozzolan or non-pozzolan effect of sludge ash, because it varies from ash to ash.

5.3 Phosphate

Phosphate is present in all living organisms as it is a part of DNA, proteins, starch and fatty acids [10]. Wastewater treatment plants cleanse, among other kinds, the domestic wastewater which is rich on excrements containting phosphate. The result of the cleanse is the sludge, of which a part is used as fertiliser, precisely because of the phosphate. The part that is not used in agriculture is burnt to ash and deposited. As part of the cleanse, phospate is extracted in the sludge as iron phosphate (Fe(III)PO₄) or aluminium phosphate (AlPO₄) by adding iron chloride (Fe(III)Cl) [46] or aluminium chloride (AlCl) [31] to avoid eutrophication in lakes and streams [47].

5.3.1 Ammonium dihydrogen phosphate (ADP)

ADP has the chemical formula $NH_4H_2PO_4$ and is formed when phosphoric acid (H_3PO_4) is combined with ammonia (NH_3) as seen in (3):

$$H_3PO_4 + NH_3 \rightarrow NH_4H_2PO_4 \tag{3}$$

It is also used as a component in dry agricultural fertiliser, because it contains both nitrogen and phosphate in a form beneficial to the plants [48].

5.4 Ion chromatography (IC)

Ion chromatography is like chromatography of a liquid. There is a mobile phase and a stationary phase. One of these phases consists of anions and the other of cations, depending on the subject of investigation. The mobile phase is led through the stationary phase with an eluent, which determines the retention time with its strength - the more powerful an eluent, the shorter retention time and higher velocity.

Depending on the test subject, the components will leave the stationary phase gradually from the components with the least affinity to the stationary phase (smallest charge) to the components with the largest affinity (largest charge) [9]. The components are then detected when leaving the stationary phase which results in a chromatogram showing each component as a graphical "top". The qualitative analysis is based upon comparing the retention time of a component with the time of a known standard. The quantitative analysis consists of comparing "tops" with a similar "top" of a known standard [7].

5.5 Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES)

The theory behind the ICP-OES method is, that the emitted light from excited atoms is measured, so that it can be converted into a content of an atom of choice, because the amount of light emitted is proportional to the atom content.

To measure the characteristic lights, plasma is formed by introducing argon to enough energy so that it splits up in charged ions and electrons. The energy in the plasma corresponds to a temperature of 5000-9000 °C. A bit of the test specimen is led into the plasma, where the atoms receive energy quantums (photons), i.e. they are excited. When the atoms leave the plasma, they release the energy quantum and a characteristic light for the atom is emitted. The signal from the light forms a top (graph), when displayed as a function of time. The area under the top can now be used in the relation (4) between itself and the concentration in the test specimen [41].

$$A = a \cdot c + b \tag{4}$$

This relation can be used together with a measured standard range, which gives a linear correlation between the top area A and the concentration c. a and b are determined through linear regression and an unknown concentration can now be determined from the top area as shown in (5) [41].

$$c = \frac{A-b}{a} \tag{5}$$

5.6 Capillary suction

When a porous material, like concrete, is placed in contact with water, the water will be transported up through the material by the capillary suction. This is a result from the wetted material which forms a concave surface (a meniscus) in a water-filled pore. Together with the hydrostatic negative pressure in the water directly under the menisci, these are decisive for one of the most important transport phenomena in porous materials – the capillary suction [33].

The total volume of water Q_{kap} which is absorbed per area unit is determined by (6).

$$Q_{\rm kap} = k \cdot \sqrt{t} = \frac{m_{\rm t}}{A} \tag{6}$$

Where $k [\text{kg}/(\text{m}^2 \cdot \sqrt{\text{t}})]$ is a constant which indicates the capillary number of the material, t [s] is the time, m_t [kg] is the dry mass and A [m²] is the area of the downward face of the specimen [33].

 $Q_{\rm kap}$ can also be found from a (Q, \sqrt{t})-diagram as the one shown in Figure 7 below.



Figure 7: Q_{kap} from a (Q, \sqrt{t})-diagram [40]

 Q_{kap} is read off of Figure 7 as the value correlating to the point, where the straight line continuation of the pre- and post-bend parts of the graph meet. The corresponding value to Q_{kap} is called $\sqrt{t_{\text{kap}}}$.

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6 Experiments and methods

Throughout the report a couple of abbreviations will be used when different mortarmixes are used. Descriptions of the full range of abbreviations of mortarmixes are shown in Table 1 below, followed by an example.

Abbreviation type	Description
5~% cement	5~% cement replacement
10~% sand	10~% sand replacement
5 cXXd	5 % cement replacement (5c) with due date of XX days (XXd)
10sXXd	10 % sand replacement (10s) with due date of XX days (XXd)
REFXXd	Reference mortar (REF) with due date of XX days (XXd) $$

Table 1:	Description	of abbreviations
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As an example, the mortarmix with a 5 % cement replacement of sludge ash will not be mentioned as "5 % cement replacement" but instead as 5 % cement. In some cases it is desirable or even necessary for the understanding to state the due date of a mortar along with the material replaced and to what extend it is replaced. As an example a 5 % cement mortar with a due date of 14 days will be mentioned as 5c14d, where 5 correlates to the replacement degree (5 %), c correlates to the material replaced by ash (cement) and 14d states the due date of the mortar (14 days).

It should be noted, that the reference mortar has no ash added, and as such is a classic mix of cement, water and sand.

6.1 Ash characteristics

6.1.1 pH-determination

The purpose of this part of the characterisation is to determine where on the pH-scale the given ash is located. The complete experimental guide is found in Appendix D.1, but below the main principles of the procedure are outlined.

The pH-value of the ash is measured potentiometrically by a pH-meter in a suspension of the ash in potassium chloride (KaCl) at a 1:2.5 ratio. The suspension is made by weighing off 5.00 g of ash into a 20.00 mL plastic vial. Next, 12.50 mL of a 1.00 M KaCl-solution is added to the ash. The plastic vial is placed on a vibration table for an hour, whereafter the ash is allowed to precipitate until the liquid phase has deposited above the ash. The pH-value is now triple determined in the liquid phase with the electrode (Figure 8a) of the pH-meter (Figure 8b).



Figure 8: Combination electrode (8a) along with the PHM 220 pH-meter (8b)

6.1.2 Water content

The objective here is to determine the content of water in the ash. It should be noted, that the ash used for the experiment has been pre-dried in a $50 \,^{\circ}$ C furnace for several days. This state of the ash will nevertheless be announced as the moist state.

Due to a triple determination, the masses of three empty beakers m_0 are measured and noted. The beakers are filled with an arbitrary amount of ash and the masses are measured and noted yet again. The beakers are now placed in a furnace at 105 °C overnight for the ash to reach a dry state. The masses of the beakers, containing the dried ash, are measured and noted. The water content of the ash is then calculated by (7).

Watercontent
$$[\%] = \frac{m_{\text{moist}} - m_{\text{dry}}}{m_{\text{moist}}} \cdot 100 \%$$
 (7)

6.1.3 Loss on ignition (LOI) cf. DS/EN 12879

The content of organic material in the ash will approximately be the achieved loss on ignition at 550 °C. Samples of dried sludge are heated in a furnace at (550 ± 25) °C. The difference in mass before and after the ignition process is used to calculate the loss on ignition (see (8)). For the ashes which are under the influence of heavy metal toxicity, the heavy metals will greatly react with the organic material in the ash and be stuck with this fraction.

Loss
$$[\%] = \frac{m_{\text{ash,before}} - m_{\text{ash,after}}}{m_{\text{ash,before}}} \cdot 100 \%$$
 (8)

6.1.4 Solubility in water

This test is conducted to light up the amount of ash, which is soluble in water. The masses of the filter before filtering the ash and after the filtering are noted. The solubility is then calculated with (9).

Solubility
$$[\%] = \frac{m_{\rm ash} - m_{\rm ash, left}}{m_{\rm ash}} \cdot 100 \%$$
 (9)

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6.1.5 Water-soluble anions

The purpose here is to determine the amount of water soluble anions with an ionchromatograph (IC).

10.00 g of dried ash is put into a 100.00 mL plastic vial. 50.00 mL of destilled water is added to the vial which is placed on a vibration table overnight. The sample is filtered through a syringe filter. The filtered sample is used in the IC.

6.1.6 Conductivity

The purpose of determining the conductivity is to get a visual of how well current is conducted in a given solution.

The procedure is conducted by weighing off 10.00 g of crushed ash into a 50.00 mL plastic vial. 15.00 mL of destilled water is then added with a full-pipette, whereafter the vial is placed on a vibration table for 30 minutes. The ash is then allowed to precipitate for approximately 20 minutes, until the liquid phase has deposited above the ash. The conductivity is then triple determined in the liquid phase with a gauge which measures it in $\frac{\text{mS}}{\text{cm}}$.

6.1.7 Destruction of ash cf. DS 259

This destruction method is a Danish Standard (DS 259) for determination of acid soluble metals. The destruction expresses the level of the concentration of metals, but not the overall concentration in the sample.

The procedure goes as follows: 1.00 g of dried, milled ash is weighed off into a autoclave bottle. 20.00 mL of half concentrated HNO₃ is added to the ash and the screw cap is tightened, since the HNO₃ would evaporate otherwise. The bottles (triple determination) are put in the autoclave at 200 kPa for 30 minutes, whereafter the bottles are cooled down to room temperature. The samples are filtered by suction through a 0.45 μ m filter in a fume cupboard. The bottle is rinsed three times with destilled water. The filtrate is poured into a 100.00 mL volumetric flask, destilled water is added up until the mark on the flask and mixed into a compound. The compound is stored in a 20.00 mL plastic vial for later use in the AAS. The result of the AAS is a guideline concentration of both heavy metals and macro elements. Once the AAS has measured the contents of metals and macros, the concentrations $\left[\frac{mg}{kg}\right]$ are calculated with (10):

$$Concentration = \frac{A \cdot 0.100 \text{ L} \cdot C}{B \cdot 10^{-3} \frac{\text{kg}}{\text{g}_{ash}}}$$
(10)

Where A is the concentration $\left[\frac{\text{mg}}{\text{L}}\right]$, B is the mass of the ash [g] and C is the attenuation factor.

6.1.8 Grain size distribution

For determining the grain size-distribution, a Mastersizer 2000 is used. Below a short description of the arrangement is presented.

The sample is introduced to a dispersion unit called Hydro SM, which makes sure that the sample is in the correct concentration when delivered to the Mastersizer 2000 [29]. The sample particles are suspended in

a dispersant that lowers the surface tension of the particles, which makes them seperate from each other and suspend better [28]. The dispersion unit is seen in Figure 9a.



Figure 9: Dispersion unit (Hydro SM) (9a) and optical bench (Mastersizer 2000) (9b)

The suspended sample is then injected into the optical bench, which is the Mastersizer itself (see Figure 9b) where the suspension is eluminated by a laser beam. The intensity of the scattered light is then captured by a series of very accurate detectors and the data is transferred to a computer with the Mastersizer 2000 software. This software analyses the data from the detectors and calculates the grain size of the particles from the respective scattering pattern [29].

6.2 Capillary suction

If the test specimens are tested for both capillary suction and porosity and density, the test for capillary suction has to be conducted first.

The test specimens are placed in an $50 \,^{\circ}$ C furnace until state of equilibrium occurs (when there is no change in the weight compared to the previous measuring). The test specimens are then placed in an exicator with silica gel to cool down to room temperature. A photo tray with racks is filled with distilled water approx 5 mm above the racks. The dimensions of the test specimens are measured before placing the specimens on top of the racks. As soon as the specimens touch the water a stopwatch is started. In intervals of 1, 2, 4, 8, 16, 32, 60 and 120 minutes the test specimens are dried with a hard wringed cloth and weighed. When the test specimens are not in contact with the water the stopwatch is stopped.

6.3 Porosity and density

The test specimens are placed in an $50 \,^{\circ}\text{C}$ furnace until state of equilibrium occurs (when there is no change in the weight compared to the previous measuring). The test specimens are then placed in an exicator with silica gel to cool down to room temperature. The weight is noted down for the test specimens before they are evacuated dry in the exicator for a minimum of three hours.

After the three hours, demineralised water (room temperature) is led into the exicator until the test specimens are fully covered in water. At this specific pressure, the specimens will stay for another hour. Air is then led into the exicator and the test specimens will stay in the water at atmospheric pressure overnight. The water saturated test specimens are first weighed in water and secondly in air (after dried with a hard wringed cloth).

6.4 Mortar casting and compressive strength

6.4.1 Preliminary part

The compressive strengths are tested for three different mixtures of cement: A reference mortar (called REF) where none of the ash is added, a 5 % cement replacement where 5 % of the cement is replaced by ash and a 10 % sand replacement where 10 % of the sand is replaced with ash. The components of the mixture for both REF, 5 % cement and 10 % sand are shown in Table 2. The mixing procedure of the cement mortar is described in Appendix A.

Specimen	Cement [g]	Water [g]	Sand [g]	Ash [g]
REF	450.0	225.0	1350.0	0.0
5~% cement	427.5	225.0	1350.0	22.5
10~% s and	450.0	250.0	1215.0	135.0

Table 2: Mortar mixes for use in testing of the compressive strength

Table 2 is also illustrated in Figure 10 below.



Figure 10: Visual comparison of mortarmixes with 5 % cement (10a) and 10 % sand (10b)

An additional 25.0 g of water is added to the mix for 10 % sand. This is a result of previous test where the mix happened to be too dry without the additional 25.0 g of water.

To determine the compressive strength, a compression test frame, ToniTechnik 3000 kN, is used. The specimens are tested until fracture and the load is noted. The compressive strength [MPa] is calculated by (11) [42]:

$$R_{\rm c} = \frac{F_{\rm c}}{1600} \tag{11}$$

where $R_{\rm c}$ is the compressive strenght in MPa and $F_{\rm c}$ is the noted force in kN.

6.4.2 Further part

For the further part different concentrations of the salt, ammonium dihydrogen phosphate (ADP), is added to the mortar to substitute pure water. This is done to see the influence of phosphate in the compressive strength progress in the early phase. Even though it is ADP added to the mix, it is, in the discussion, assumed that only pure phosphate is added. The four different concentrations are respectively 0.10 M, 0.25 M, 0.50 M and 1.00 M. The addition of ADP to each solution appear from Table 21 in Appendix C. Both REF and 5 % cement are conducted for the four different concentrations. The appurtenant ADP solutions for each concentration are shown in Table 3.

Concentration [M]	ADP solution [mL]
0.10	225.0
0.25	235.0
0.50	250.0
1.00	275.0

Table 3: Concentration and appurtenant ADP solution

Additional ADP solution is added to both the concentrations of 0.25 M, 0.50 M and 1.00 M compared to 0.10 M. This is a result of previous test where the mixes happened to be too dry without the additional water.

Regarding the mixing procedure for the ADP solutions the procedure described in Appendix C is used.

6.5 Setting time and hardening

To determine the setting time of a hydraulic cement mortar, the Automatic Vicat CE350 apparatus is used (see Figure 11). The Vicat penetrates a mortar sample with a probe in certain time intervals over a preset time period. This yields a series of coordinates in the form of (p,t) with p [mm] being the penetration distance and t [min] being the time. The hardening process can then be sketched and the setting time determined.



Figure 11: The Automatic Vicat CE350 apparatus [17]

Before using the Automatic Vicat apparatus, it should be calibrated cf. the Impact Test Equipment Ltd. operating manual [27]. The correct use of the apparatus should also be conducted cf. the Impact Test Equipment Ltd. operating manual [27].

The components of the mixture for both REF, 5 % cement and 10 % sand are the same as shown in Table 2. The mixing procedure of the cement mortar is described in Appendix A.

6.6 Flow of hydraulic cement mortar

The purpose of this experiment is to determine the flow of hydraulic cement mortar. The flow of a cement mortar can be used to determine whether it contains the right amount of water by fulfilling a specified flow. The conduction of the flow test cf. ASTM C1437-07 [18] is to be found in Appendix B.

7 Results and discussion

7.1 Work process

Through initial testing with the sludge ash, a load of results were modelled to form a poster presentation (see Appendix F), which founded the base for the further work of the project. Figure 12 shows how the work process was determined.



Figure 12: Work process for the project

As seen from Figure 12 the project started off broadly. After the preliminary tests with the ash leading to the poster presentation, the project was narrowed in, due to findings of a high phosphate content in the ash, combined with observations of slower setting and lower strength as the ash replacement increased. These factors lead to the final delimitation of the project: Impact of phosphate on the compressive strength of the mortar in the early phase.

7.2 Ash characteristics

DS 2426 [44] contains supplementary standards and elaborations to DS/EN 206-1 and DS/EN 206-9, which are essential for using these in Denmark. DS 2426, DS/EN 206-1 and DS 206-9 can only be used as one whole, and none of the three standards can be used separately. In case of contradiction, DS 2426 is valid before DS/EN 206-1.

According to DS 2426 [44] sludge ash, as a waste product by combustion of wastewater sludge from Danish wastewater treatment plants, has to be delivered with an informative label, which as a minimum declares the chemical parameters cf. DS/EN 450-1, 5.2 [6] and a particle density cf. DS/EN 450-1, 5.3.4 [6], to be used as an admixture to the concrete. Furthermore, the loss of ignition for sludge ash has to meet the standards for category A cf. DS/EN 450-1.

Table 4 shows the chemical requirements of sludge ash cf. DS 2426 and DS/EN 450-1.

Chemical parameter	Method	Required values
Loss on ignition	EN 196-2	<5.0 %
Chloride	EN 196-2	< 0.1 %
Sulphate content	EN 196-2	$<\!3.0~\%$
Free calcium oxide	EN 451-1	$<\!\!1.5~\%$
Reactive calcium oxide	EN 197-1	$<\!10~\%$
Reactive silicon dioxide	EN 197-1	> 25 %
Silicon dioxide (SiO_2) Aluminium oxide (Al_2O_3) Iron oxide (Fe_2O_3)	EN 196-2	∑>70 %
Total content of alkalis Magnesium oxide	EN 196-2 EN 196-2	< 5.0 % < 4.0 %
Phosphate	ISO 29581-2	<5.0 %
Particle density	EN 1097-7	$\pm 200 \frac{\text{Kg}}{\text{m}^3}$

Table 4: Chemical requirements for fly ash

All the required values in Table 4 are % by mass and the particle density is not allowed to deviate more than $\pm 200 \frac{\text{kg}}{\text{m}^3}$ from the value declared by the producer.

The Danish consolidation Act no. 1662 from 24-12-2010 [5] determines the rules for the application of waste products and soil in construction work. The consolidation Act does cover fly ash but not sludge ash. However, the Act is still found to give a good indication of the threshold values for sludge ash and it will therefore be used in discussion of the ash characteristic. Table 5 indicates the threshold values of waste products and soil in construction work.

Substance	Category 1 $\left[\frac{mg}{kg}\right]$	Category 2 $\left[\frac{mg}{kg}\right]$
Arsenic	0 - 20	> 20
Lead	0 - 40	> 40
Cadmium	0 - 0.5	> 0.5
Chromium, total	0 - 500	> 500
Chromium (VI)	0 - 20	> 20
Copper	0 - 500	> 500
Mercury	0 - 1	> 1
Nickel	0 - 30	> 30
Zinc	0 - 500	> 500

Table 5: Classification of waste products and soil into categories

The threshold values in Table 5 are classified in two categories. If the threshold values are conformed to category 1 the waste products and soil can be used, without sanction, for all construction work. In category 2 there are different requirements cf. Lovtidende 1662 [5]. Actually there is a category 3, but this category has the same threshold values as category 2 and is therfore left out.

7.2.1 Data from Lynettefællesskabet I/S

In connection with delivery of the sludge ash from Lynettefællesskabet I/S an Executive Order on Work with Substances and Materials and a safety data sheet was included (see Appendix E). From Table 6 the

content of substances, according to Lynettefællesskabet I/S, in the sludge ash are shown.

Substance	Content [%]
Calcium oxide (CaO)	10 - 15
Silicon dioxide (SiO ₂)	25 - 35
Aluminium oxide (Al_2O_3)	5 - 10
Iron oxide (Fe_2O_3)	10 - 15
Phosphorpentaoxid (P_2O_5)	20 - 25

Table 6: Content of substances

From Table 6 the content of CaO in the sludge ash is between 10 and 15 %. It does not appear from the information from Lynettefællesskabet I/S if dealing with reactive or free calcium oxide. Regardless of this, the content between 10 and 15 % will still be higher than the highest required value of 10 % for reactive CaO.

The content of SiO₂ is between 25 and 35 % and fulfills the required value of minimum 25 %. Silica in concrete reacts with Ca(OH)₂, which is formed by the hydration of the cement, and thereby contributes as a binding material in the concrete. This reaction is called a pozzolanic reaction. Aluminium oxide and iron oxide take some kind of part in similar reactions as for silicon dioxide. The existence of these three oxides gives an indication if a given waste product can be presumed to have pozzolanic properties and thereby contribute to the development of the strength and denseness in the concrete. The content of both silicon dioxide, aluminium oxide and iron oxide has to be bigger than 70 % as shown in Table 4. If adding together the highest value in the interval for these three substances (from Table 6), it only sums up to 35 % + 10 % + 15 % = 60 %. This is 10 % from the required value.

7.2.2 pH-determination

Below in Table 7 the pH-measurements for the three test specimens are shown along with an average pH-value.

Specimen	$_{\rm pH}$
А	11.9
В	11.8
\mathbf{C}	11.7
Average	11.8

As Table 7 shows, the suspended ash is measured to have an average pH-value of 11.8, which is quite alkaline.

7.2.3 Water content

The water content of the ash is calculated from (7). Table 8 below presents the measured data along with the calculated water contents.

Specimen	m_0 [g]	$m_{\rm moist}$ [g]	$m_{\rm dry} \; [{\rm g}]$	Water content $[\%]$
А	18.62	24.25	24.24	0.041
В	18.58	25.87	25.85	0.077
\mathbf{C}	19.09	25.83	25.80	0.116
Average				0.078

Table 8: Water content

Table 8 shows an average for the water content, because of rather significant deviations between the test specimens (deviation between A and C ≈ 180 %). These deviations makes a conclusion difficult to draw, which is the reason for the presentation of an average percentage of 0.078.

7.2.4 Loss on ignition (LOI) cf. DS/EN 12879

The measured data are shown along with the calculated results from (8) in Table 9 below.

Specimen	m_0 [g]	$m_{\rm ash, before}$ [g]	$m_{\rm ash, after}$ [g]	Loss on ignition [%]
А	13.71	17.33	17.33	0.00
В	14.22	17.65	17.66	$-0.06 \simeq 0.00$
\mathbf{C}	13.80	17.81	17.81	0.00
Average				0.00

Table 9: Loss on ignition

In Table 9 it is seen that there was no organic material present at the time of the conduction of the incineration process. Because organic material eventually decomposes, it should only be seen as a good property of the ash that it contains no organic material. Due to the decomposition, the organic material would leave air voids, causing the concrete to be more susceptible to different sorts of environmental attacks, e.g. frost or chemical. Compared to Table 4 the LOI of 0.00 % does not exceed the limit of 5 %.

7.2.5 Solubility in water

In Table 10 the masses of the filter before and after the test are shown.

Table 10: Solubility in water

$m_{\rm filter, before}$ [g]	$m_{\rm filter,after}$ [g]	$m_{\rm ash, left}$ [g]
9.88	106.68	96.80

With the data from Table 10 the solubility is calculated with (9) and gives (12).

Solubility
$$[\%] = \frac{100 \text{ g} - 96.8 \text{ g}}{100 \text{ g}} \cdot 100 \% = 3.20 \%$$
 (12)

This means, that out of 100.00 g of ash, 3.20 g are dissolved in the water, which consequently means that there is a loss of solid matter. The conduction of the solubility test is of a slightly uncertain character,

since it requires that every single bit of ash is accounted for, when weighing the filter (see Appendix D.4). If not, the solubility appears higher than it actually is. A way to see whether the solubility is reasonable is to test the content of soluble anions with ion chromatography (see section 5.4).

The solubility is a measure of how much solid material dissolves in water (splitting up into ions). This means, that the measured amount of soluble anions with the IC should constitute about half of the total solubility from (12). The reason why it should only constitute half is that the anions have appurtenant cations constituting the other half. Of course there are other water soluble substances present in the ash than ions, which the rest of the solubility can be assigned to (still with some degree of uncertainty in mind).

The content of soluble anions from the IC are presented in section 7.2.6, followed by a further discussion.

7.2.6 Water-soluble anions

In Figure 13 below the concentrations of the different anions are shown.



Concentrations of water-soluble anions

Figure 13: Concentrations of water-soluble anions

Figure 13 shows the concentrations of Cl^- , NO_3^- and SO_4^{2-} . The corresponding percentages are presented in Table 11 below.

Table 11: Corresponding %	of C	1 ⁻ , NO ₃ ⁻	and SC	$)_4^{2-}$
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Anions	Content [%]
Cl-	0.02
NO_3^-	0.0007
SO_4^{2-}	1.27
\sum Anions	1.29

Compared to the solubility from 7.2.5 of 3.20 % the total content of anions sums up to 1.29 % which according to the discussion in 7.2.5 should be about half of the total solubility. If the content of soluble anions is doubled the result is 2.58 %, which seems quite reasonable, since there as mentioned, are other soluble substances along with some degree of uncertainty. The comparative deviation between the

total solubility and the ion solubility is calculated in (13) stating a combined margin of other dissolved substances and uncertainty.

Deviation
$$\% = \frac{3.20 \% - 2.58 \%}{3.20 \%} \cdot 100 \% = 19.38 \%$$
 (13)

The deviation of 19.38 % should include the presence of other soluble substances and uncertainties in connection with experiment conduction.

If comparing Table 11 with Table 4 the chloride content of 0.02 % satisfy the requirement of less than 0.1 %.

7.2.7 Conductivity

Below in Table 12 the measured $\frac{mS}{cm}$ are shown along with an average value.

Specimen	$\left[\frac{\mathrm{mS}}{\mathrm{cm}}\right]$
А	3.26
В	3.30
\mathbf{C}	3.25
Average	3.27

Table 12: Conductivity

The results from Table 12 shows an average conductivity of $3.27 \frac{\text{mS}}{\text{cm}}$, which compared to a value of 7.81 $\frac{\text{mS}}{\text{cm}}$ from 2013 [40] is rather low. Since this report and the report of Morten Reiff et al (2013) [40] deal with the same ash it seems peculiar that there is such a significant difference in the conductivities. It is the content of readily soluble salts that decide the degree of conductivity. This means, that the content of salts has dropped significantly from 2013 to 2014. This does not give any meaning however, if the ash came directly from the furnace.

Since the conductivity of stored ash from the report of Morten Reiff et al (2013) [40] has a value of 5.59 $\frac{mS}{cm}$ it makes more sense, if the ash subjected in this report was extracted from storage as well. The difference in conductivity could then be explained by the fact, that some of the soluble salts are washed out of the ash, because it is exposed to rain and snow. That way it seems reasonable that the value has dropped as much as it has from 2013 to 2014. The conductivity has to be said to vary between ashes and even between batches of the same ash.

7.2.8 Destruction of ash cf. DS 259

7.2.8.1 Heavy metals

If considering heavy metals from a concrete-technical perspective, the content has no importance for the primary properties of the concrete. On the other hand the heavy metals are unwanted in the concrete seen from an environmental view by several reasons e.g. by satisfying demands in the quality of the wastewater and solid waste. In Figure 14 the shares of several different heavy metals, arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn), in the ash are shown.



Content of heavy metals

Figure 14: Content of heavy metals

If comparing Figure 14 with Table 5 it can be found which category each heavy metal belongs to according to [5]. The comparison is shown in Table 13 where the actual content for each substance along with the appurtenant category is shown.

Content $\left[\frac{\mathrm{mg}}{\mathrm{kg}}\right]$	Content $[\%]$	Category
1	0.0001	1
3	0.0003	2
53	0.01	1
-	-	-
629	0.06	2
-	-	-
19	0.002	1
30	0.003	1
$3,\!552$	0.36	2
	Content $\left[\frac{mg}{kg}\right]$ 1 3 53 - 629 - 19 30 3,552	$\begin{array}{c c} {\rm Content} \left[\frac{{\rm mg}}{{\rm kg}} \right] & {\rm Content} \left[\% \right] \\ \hline 1 & 0.0001 \\ 3 & 0.0003 \\ 53 & 0.01 \\ \hline \\ - & - \\ 629 & 0.06 \\ \hline \\ - & - \\ 19 & 0.002 \\ 30 & 0.003 \\ 3,552 & 0.36 \\ \end{array}$

Table 13: Content and category of heavy metals

It does not appear from the test results in which state chromium is detected (chromium (VI) or other). The result for chromium is therefore placed in "Chromium, total" where "Chromium (VI)" is left blank. Furthermore, there is no results for mercury which is also left blank.

Three out of the seven heavy metals exceed the threshold values of category 1. This concerns cadmium, copper and zinc. The content of Cd is 500 % higher than the threshold value, Cu is 26 % higher and Zn is 610 % higher. It is rather safe to say, that the wastewater is the source of the significant concentration of zinc, since the content of zinc in wood-charcoal ash is about 1800 $\frac{\text{mg}}{\text{kg}}$, which is around 50 % of the content in the sludge ash.

These three substances place the sludge ash in category 2 cf. [5] and can therefore only be used in construction work with different requirements according to [5].

7.2.8.2 Macro elements

Figure 15 expresses the level of concentrations of aluminium (Al), magnesium (Mg), sodium (Na), potassium (K) and phosphate (P).



Figure 15: Content of macro elements

The only alkalis found in this test are Na (Na₂O) and K (K₂O). The alkali-ions causes the rise in the pH-value of the concrete. If adding a reactive aggregate, a gel consisting of alkali-silica or alkali-carbonate can be formed. The gel attracts water which builds up a high pressure in the gel that harms the concrete. A high pH-value can also have some positive effects and in some cases accelerate the strength development of the concrete. The total content of alkalis appear from (14).

$$\sum \text{alkalis} = \frac{\frac{1}{2} \cdot 4,788 \frac{\text{mg}}{\text{kg}} + \frac{1}{2} \cdot 10,486 \frac{\text{mg}}{\text{kg}}}{10^6 \frac{\text{mg}}{\text{kg}}} \cdot 100 \% = 0.76 \%$$
(14)

As seen in (14) the total content of alkalis found in the sludge ash is 0.76 % which is less than the required value of 5 % found in Table 4.

As Figure 15 shows, the content of phosphate is 93,794 $\frac{\text{mg}}{\text{kg}}$ which corresponds to a content of 9.38 %. This value is approximately 10 times higher than that of conventional fly ash (approx. 1 % [32]). This high content of phosphate is 4.38 % higher than the required value shown in table 4 and is reckoned to be of interest, since extraction of the phosphate from the ash is a potential source of business, but also because it could have an effect on the mechanical properties of concrete. On account of these thoughts, the effect of phosphate will be enlightened through experiments on the compressive strength of concrete (see section 7.7.2 and onwards).

Magnesium oxide can react with water and cause damaging expansions. The content of Mg (MgO), is 18,189 $\frac{mg}{kg}$ corresponding to 1.82 % and is lower than the required value of 4 % from Table 4.

7.2.9 Summary of ash characteristics

It is not possible to compare the found values from the ash characterisation directly with the required values in Table 4. This table shows only the required values of fly ash cf. to DS/EN 450-1 [6]. However, DS 2426 [44] opens up for using sludge ash as a type II-addition but only if the values shown in Table 4.

are satisfied. These requirements makes it difficult to use sludge ash in the production of concrete. On one hand you can say that if the unwanted substances exceed the required values, known from fly ash, on an early stage, it is highly possible they will not be suitable in the production of concrete. On the other hand, fly ash and sludge ash are two independent and different products and should therefore not be handled the same way. Of course they have to meet some of the same threshold values but there has to be made specific requirements for sludge ash as seen for fly ash as they are two different products.

7.2.10 Grain size distribution

7.2.10.1 Non-milled ash

In Figure 16 below the distribution of grain size for a non-milled sample of the ash is shown.



Grain size distribution, non-milled

Figure 16: Double determination of grain size distribution for non-milled ash

Figure 16 shows that the grain sizes of the two samples are not alike, which indicates, that the ash has to be milled before using it in concrete in order to obtain an as homogeneous mix as possible. The result of the milling is shown in section 7.2.10.2.

7.2.10.2 Milled ash

The grain size distribution for a milled sample is shown in Figure 17.


Grain size distribution, milled

Figure 17: Double determination of grain size distribution for milled ash

As opposed to the grain size distribution in Figure 16 the distrubution in Figure 17 shows a far more uniform size distribution for the milled ash, which makes the ash applicable.

7.3**Capillary** suction

Below in Figure 18 the capillary suction measurements of the 5 % cement mortars are shown.



Capillary suction for 5 % cement

Figure 18: Capillary suction for the 5 % cement

From Figure 18 it is noted, that 5c14d, 5c28d and REF28d have quite alike progressions, which in this discussion will be interpreted as if they were exactly the same. On that behalf, it is assumed that there is no difference between the three progressions. This assumption seems reasonable since whatever difference there might be can probably be assigned to uncertainties to a significant extend.

The difference between the progress of 5c7d and the others makes good sense however. The diagram expresses how much water has been sucked up into the capillary pores, i.e. how large a capillary volume is present in the mortar specimen at the given due date. Since the hydration process continues until there is no more cement particles to hydrate, the formation of hydration product mentioned in section 5.1.1 continues as well. This means, that a specimen with a due date of 7 days has not hydrated to the same degree as for instance a specimen with due date of 14 or 28 days. Therefore the hydration products have not yet filled out the capillary pores to the same extend. The "young" specimen consequently has a higher capillary suction, since there are more capillary pores present.

Figure 19 shows the capillary suction measurements of the 10 % sand mortars.



Capillary suction for 10 % sand

Figure 19: Capillary suction for the 10~% sand

As assumed for Figure 18, it is assumed for Figure 19, that the graphs for 10s7d, 10s14d and REF28d have the same progress. This assumption is due to the fact, that 10s7d has less capillary suction than both the 10s14d and the REF28d, which should not be the case. This is assumed to be uncertainties and the three mentioned specimens are therefore accounted for as being alike.

The difference in capillary suction between the 10s28d and the REF28d (including 10s7d and 10s14d) can be explained rationally. Replacing sand with ash means removing a material with more pores and adding a material with a high degree of packing, resulting in less pores. With this fact in consideration, it makes perfect sense, that the specimen containing more of a coarse material contains more air than a specimen containing less coarse material and more of a fine material. Consequently the porous specimen sucks up more water into the capillary pores than the dense specimen.

7.4 Porosity and density

Figure 20 shows the open porosity p_{open} for the two different replacement options (5 % cement and 10 % sand) after 7, 14 and 28 days.



Porosity of mortarmixes

Figure 20: Porosity of mortarmixes

The measured porosities between 18 % and 22 % are consistent with a reference value of 20 % [33].

As seen from Figure 20, the general rule is, that the 10 % sand substitution gives a higher porosity than that of the 5 % cement replacement. This result is due to the w/c-ratio. A high w/c-ratio gives a high porosity. On that behalf the w/c-ratios for the 5 % cement, 10 % sand and REF are calculated in (15), (16) and (17).

$$w/c_{5\% \text{ cement}} = \frac{225.0 \text{ g}}{427.5 \text{ g}} = 0.53$$
 (15)

$$w/c_{10\% \text{ sand}} = \frac{250.0 \text{ g}}{450.0 \text{ g}} = 0.56$$
 (16)

$$w/c_{\rm REF} = \frac{225.0 \text{ g}}{450.0 \text{ g}} = 0.50$$
 (17)

As seen from the calculations, the REF has the lowest w/c-ratio which correlates to the fact, that it also has the lowest porosity of the three specimens after 28 days. After 7 and 14 days, the 5 % cement also has a lower porosity than the 10 % sand. This is explained by the lower w/c-ratio.

In Figure 21 the dry density ρ_d is shown along with the density in saturated, surface dry state ρ_{ssd} .



Density of mortarmixes



The dry densities seen in Figure 21 are approx between 2050 $\frac{\text{kg}}{\text{m}^3}$ and 2100 $\frac{\text{kg}}{\text{m}^3}$ which correlates well to a reference range of 2000-2400 $\frac{\text{kg}}{\text{m}^3}$ [34].

Figure 21 shows, that the dry densities ρ_d of the 5 % cement mortars are slightly higher than of the 10 % sand mortars. This is explained by the mass and amount of which material is replaced with sludge ash. In the 5 % cement all of the 1350.0 g of sand are used and 22.5 g of the cement is replaced with ash (see Table 2 and Figure 10). In the 10 % sand mix, 1215.0 g of sand are used and 135.0 g of sand are replaced with sludge ash. In the 10 % sand, sand is removed, reducing the density notably because sand has a higher density than sludge ash. The density of the 5 % cement has not changed in the same degree, because the difference in density between cement and ash is not as large. In short terms; the removed sand from the 10 % sand reduces the density more than the ash added instead of cement in 5 % cement increases the density.

It is also noted, that both the dry state density and the saturated, surface dry state density do not change significantly from 7 to 28 days. The largest deviations for the dry state densities for 5 % cement and 10 % sand are calculated in (18) and (19) respectively.

Deviation<sub>5% cement,
$$\rho_{\rm d} \% = \frac{2110.44 \ \frac{\rm kg}{\rm m^3} - 2102.48 \ \frac{\rm kg}{\rm m^3}}{2110.44 \ \frac{\rm kg}{\rm m^3}} \cdot 100 \ \% = 0.38 \ \%$$
(18)</sub>

Deviation<sub>10% sand,
$$\rho_{\rm d} \% = \frac{2074.00 \ \frac{\rm kg}{\rm m^3} - 2048.03 \ \frac{\rm kg}{\rm m^3}}{2074.00 \ \frac{\rm kg}{\rm m^3}} \cdot 100 \ \% = 1.25 \ \%$$
(19)</sub>

7.5 Flow of hydraulic cement mortar

The results of the flow test for REF, 5 % cement and 10 % sand are seen in Table 14 below.

Mix	$D_1 \ [mm]$	$D_2 \ [mm]$	Average [mm]
REF	158.0	156.0	157.0
5~% cement	148.0	144.0	146.0
10~% s and	144.5	142.0	143.3

Table 14: pH-determination

It appears from Table 14 that the REF has the highest average flow, because it has the biggest diameter. The 5 % cement and 10 % sand follow in the mentioned order, which indicates an effect of the sludge ash on the flow of the mortar. Because the ash has such a big surface area, it packs itself in a high degree in between the other particles in the mix, creating bigger surface tension between the particles, resulting in a smaller flow.

Accordingly it is reasonable, that it is the 10 % sand, that has the lowest flow, because it has the most ash added, which is much finer than sand. For the 5 % cement, the packing factor is present as well, but given that it does not contain as much ash as the 10 % sand the lower flow is due to the fact that the packing of the ash "happens" before the hydration of the cement, i.e. the setting.

7.6 Phosphate solubility

As part of the initial testing of the ash a destruction was conducted in order to determine the content of different macros in the ash. The results showed, that 9.38 % of the ash was phosphate, which lead towards a further investigation of the effect of phosphate. Since the destruction of the ash is conducted using 1/1 HNO₃ to determine the total content, it was reasoned that this procedure was not optimal for testing how much phosphate is liberated from the ash when mixed into cement mortar. The cement is highly alkaline with a pH-value of approx 13 [39] and so is the sludge ash with a pH of 11.8 as shown in Table 7.

With these pH-values, it was found relevant to test how much of the chemically bound phosphate would be liberated in a base such as NaOH with a pH of 12.8 (measured cf. Appendix D.1). As an illustration of how hard the naturally occuring phosphate is bound as whitlockite tri-calcium phosphates $Ca_3(PO_4)_2$ [4], the destruction has been conducted with regular destilled water. Figure 22 shows the results of the acidic, alkaline and neutral destruction.



Phosphate solubility in HNO_3 , NaOH and H_2O

Figure 22: Solubility of phosphate (P) in HNO₃, NaOH and H₂O

Below in (20) the share of the total amount of phosphate from the acidic destruction, is calculated along with the share of alkaline soluble phosphate in (21), which in practice has a more direct connection to the negative effect on the compressive strength of concrete. The water soluble share is calculated in (22).

$$P_{\rm HNO_3} = \frac{93794 \, \frac{\rm mg}{\rm kg}}{10^6 \, \frac{\rm mg}{\rm kg}} \cdot 100 \, \% = 9.38 \, \% \tag{20}$$

$$P_{\text{NaOH}} = \frac{69670 \frac{\text{mg}}{\text{kg}}}{10^6 \frac{\text{mg}}{\text{kg}}} \cdot 100 \% = 6.97 \%$$
(21)

$$P_{\rm H_2O} = \frac{3 \frac{\rm mg}{\rm kg}}{10^6 \frac{\rm mg}{\rm kg}} \cdot 100 \ \% = 0.0003 \ \% \tag{22}$$

As seen from the chart (Figure 22) and (20) the total amount of phosphate from the acidic destruction correlates to 9.38 % of the ash, whereas the alkaline soluble phosphate correlates to 6.97 % as seen in (21) and the water soluble phosphate is no less than 0.0003 %, which is practically non-existing. These results show, that of all the phosphate in the ash (93,794 $\frac{\text{mg}}{\text{kg}}$), 74.28 % (69,670 $\frac{\text{mg}}{\text{kg}}$) of it is soluble in NaOH.

According to DS 450-1 the total phosphate content of fly ash can constitute no more than 5 % in the mortar [6]. To compare the actual share of phosphate to DS 450-1, the percentages are calculated below in (23)-(25) for REF, 5% cement and 10% sand with compositions as expressed in Table 2. It should be noted, that the percentages are calculated with respect to the total mass of dry material in the mortarmix.

$$P_{\text{REF}} = \frac{m_{\text{P}}}{m_{\text{cement}} + m_{\text{sand}} + m_{\text{ash}}} = \frac{0.0938 \frac{\text{kg}}{\text{kg ash}} \cdot 0.0 \text{ kg ash}}{2.025 \text{ kg}} \cdot 100 \% = 0.00 \%$$
(23)

$$P_{5\% \text{ cement}} = \frac{m_{\rm P}}{m_{\rm cement} + m_{\rm sand} + m_{\rm ash}} = \frac{0.0938 \frac{\text{kg}}{\text{kg ash}} \cdot 0.0225 \text{ kg ash}}{2.025 \text{ kg}} \cdot 100\% = 0.10\%$$
(24)

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$$P_{10\ \% \text{ sand}} = \frac{m_{\rm P}}{m_{\rm cement} + m_{\rm sand} + m_{\rm ash}} = \frac{0.0938 \frac{\rm kg}{\rm kg \ ash} \cdot 0.135 \ \rm kg \ ash}{2.025 \ \rm kg} \cdot 100\ \% = 0.63\ \% \tag{25}$$

The shares of phosphate in all three mixes are nowhere near the 5 % limit. With a little backwards calculation approx 1.1 kg of the cement and sand would have to be replaced with sludge ash for the mortar to reach a phosphate content of 5 %.

7.7 Compressive strength test

7.7.1 Preliminary part

The REF-tests are conducted in cooperation with the project family for 1, 2, 3, 4, and 5 days while the 5 % cement and 10 % are conducted with the "Lynette-ash" for 1, 3 and 5 days. The results are evident in Figure 23 and Table 15.



Compressive strength test

Figure 23: Compressive strength test

Table	15:	Compressive	strength	test

Days	$R_{\rm c, REF}$ [MPa]	$R_{ m c, 5~\%~cement}$ [MPa]	$R_{ m c,\ 10\ \%\ sand}$ [MPa]
1	20.2	20.1	19.7
2	29.2	-	-
3	40.7	36.7	39.0
4	41.4	-	-
5	45.9	38.5	43.1

It is shown from Figure 23 that the strengths are almost identical for the three mixtures after 1 day in the range from 19.7-20.2 MPa with the strength of REF only 2,5 % higher than the lowest strength (in this case 10 % sand).

After 3 days some tendencies are showing; REF has the highest compressive strength (40.7 MPa) which is 10.9 % higher than the lowest (in this case 5 % cement). 10 % sand lies in between these two mixtures with a strength 4.2 % lower than REF. The same tendencies are in evidence after 5 days. The compressive strength for REF has attained 45.9 MPa which is 19.2 % higher than 5 % cement and 6.5 % higher than 10 % sand.

These results shown in Figure 23 tell that when adding the ash to the mixture, the compressive strength will be lower compared to the reference mortar where none of the ash is added and that the 5 % cement is weaker than the 10 % sand. The reduced strength of the 5 % cement is the consequence of removing cement from the mix, because it is the hydration of cement that forms reaction products responsible for the strength development of the mortar cf. section 5.1.1.1. When cement is replaced with sludge ash, the compressive strength is reduced. It leads to the conclusion, that the added sludge ash apparently does not have pozzolanic effect, i.e. it does not form chemical products when introduced to water, but probably contributes to the mortar with a somewhat high degree of packing due to its fineness.

In the 10 % sand on the other hand, all the cement is kept and some of the sand is replaced with ash. According to the previous discussion of the reduced strength of the 5 % cement, the higher strength of the 10 % sand can be assigned to the amount of cement. The reason for the lower strength, of the 10 % sand compared to the REF, could be a reduction of chemical reactions and hydration products, since the ash compared to sand packs itself more tightly around the cement particles reducing the water influx and ultimately slows down or reduces the hydration of the cement.

An overall conclusion to the compressive strengths when sludge ash is added, is that the mortars do not develop the optimal early age strength compared to the REF mortar. For both the 5 % cement and the 10 % sand this could be due to an interference with the realtionship between water and cement. Either the w/c-ratio is physically changed by removing cement from the 5 % cement or it could be said to be changed in practice in terms of reducing the water flow to the cement particles by adding ash which can prevent the water from getting to the cement in an optimal fashion.

7.7.2 Further part

For the further part of the project, it was chosen to subject the 5 % cement to additional testing. This was due to the result showing that 5 % cement had approx the same compressive strength as the REF in Figure 23. Furthermore, by replacing the cement with ash, the largest savings are obtained. Accordingly, it is the 5 % cement that is most relevant to investigate further.

The mixing method for cement mortar cf. DS/EN 196-1 does not include a mixing procedure if a solution is used instead of pure water [42]. In spite of this detail, the mixing procedure described in Appendix A is still used while it is supposed that following the standardised method will give results that can be compared. The water can, according to DS/EN 196-1 [42], be added as a mass or as a volume. This makes good sense when the water has a density of 1000 $\frac{\text{kg}}{\text{m}^3}$, but it makes up a slight dilemma when adding the ADP-solution where the density is different from 1000 $\frac{\text{kg}}{\text{m}^3}$; Either 225 mL (with a mass greater than 225 g) or 225 g (with a volume less than 225 mL) can be added.

In this test is has been chosen to use the volume (225 mL) of the ADP-solution because it is assumed to give more water molecules to the hydration process compared to adding the solution as a mass.

The plan from the beginning was to make a 0.10 M solution, a saturated solution (in this case 3.25 M for ADP) and a solution between these (1.00 M). The saturated solution was found to be impossible to mix. The mixture hardened immediately when the water was added which made it impossible to use. At the same time a highly exothermic process was observed with an increase in temperature of at least 30 °C (it is not precisely known, since the thermometer scale went up to just 50 °C).

Figure 24 and Table 16 show the strength development of REF after 1, 3 and 5 days for 0.10 M, 0.25 M, 0.50 M and 1.00 M of ADP-solution respectively. The development is also shown only with demineralised water (DM water) where no ADP is added.



Compressive strength test, REF

Figure 24: Compressive strength test, REF

Table 16:	Compressive	strength	test, REF
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Days	$R_{ m c, DM}$ [MPa]	$R_{c, 0.10 M}$ [MPa]	$R_{c, 0.25 M}$ [MPa]	$R_{c, 0.50 M}$ [MPa]	$R_{c, 1.00 M}$ [MPa]
1	20.2	21.5	5.8	-	4.6
3	40.7	40.1	32.8	15.4	17.0
5	45.9	47.3	43.0	32.5	24.1

From Figure 24 it is shown that adding phosphate to the mixture has a significant impact on the strength development in the early phase (1-5 days). If comparing with Figure 23 where the strengths are almost identical after 1 day, a big spread in the compressive strength for the four concentrations is seen already after 1 day. 0.10 M has the highest strength with 21.5 MPa but is only 6.4 % higher than the DM water. 0.25 M (5.8 MPa) and 1.00 M (4.6 MPa) are close as well. It was not possible to test 0.50 M after 1 day because the specimens were not hardened enough to be demoulded without cracking. Therefore the

demoulding was delayed 24 hours for 0.50 M (both 3 and 5 days) cf. DS/EN 196-1 [42]:

"Demoulding may be delayed by 24 h if the mortar has not acquired sufficient strength at 24 h to be handled without risk of damage."

After 5 days 0.10 M still has the highest compressive strength (47.3 MPa) and is 3.1 % higher than DM water. 0.25 M has obtained a lot of strength in the same period and approximates 0.10 M and DM water with a strength of 43 MPa. Between 3rd and 5th day 0.50 M has overhauled 1.00 M and ends up with a strength of 32.5 MPa compared to 24.1 MPa for 1.00 M.

A tendency where the compressive strength decreases when the concentration increases is in evidence after 5 days, except for 0.10 M which is slightly higher than DM water. It could seem, that there has been a successful isolation of a range for the limit value of how much phosphate can be added without it having an effect on the strength of the mortar. This conclusion is derived from the reasoning that the 0.10 M and the DM water are of the same strengths, with some measuring uncertainty in mind. On that behalf, the limit concentration value is expected to be in the range 0.10-0.25 M, since the strength of the 0.25 M has a significantly lower strength, that probably cannot be explained by any measuring uncertainties.

Figure 25 and Table 17 show the strength development of 5 % cement after 1, 3 and 5 days for 0.10 M, 0.25 M, 0.50 M, 1.00 M and with only DM water respectively.



Compressive strength test, 5 % cement

Figure 25: Compressive strength test, 5 % cement

Days	$R_{\rm c, DM}$ [MPa]	$R_{c, 0.10M}$ [MPa]	$\begin{array}{c} R_{\rm c, \ 0.25M} \\ [\rm MPa] \end{array}$	$R_{c, 0.50M}$ [MPa]	$R_{c, 1.00M}$ [MPa]
1	20.1	16.7	7.0	-	4.1
3	36.7	37.9	32.4	17.2	15.4
5	38.5	41.0	39.1	32.7	20.6

Table 17: Compressive strength test, 5 % cement

If comparing Figure 25 with Figure 24 some of the same tendencies are seen, e.g. that an increase in the solution concentration gives a lower compressive strength. Generally the main difference is that the compressive strength is lower for 5 % cement than REF. This concerns all test specimens except from 0.50 M. 0.50 M has a 1.8 MPa higher strength after 3 days and 0.2 MPa higher after 5 days for the 5 % cement compared to the REF. Furthermore, the DM water starts with a 3.4 MPa higher strength than 0.10 M after 1 day. The DM water ends up with a lower strength after 5 days though, as it is also seen for the REF.

At the same time 0.25 M ends 0.6 MPa higher than DM water after 5 days, which could signal, that the ash has a greater negative impact on the mortars with little or no ADP-solution in it. This can be derived from the drop in strength for the DM water, 0.10 M and 0.25 M, which have decreased with 16.1 %, 14.0 % and 9.1 % respectively.

Besides the interpretation of the strengths, the narrowing down of a range in which to find the limit value of phosphate is not as clear as for the REF. In principle, the range 0.10-0.25 M obtained from the results of the REF, has to be extended to 0.10-0.50 M as a consequence of the somewhat equivocal results of the 5 % cement. Accordingly, it is highly relevant to establish how large the concentration of phosphate actually is, in order to compare it to the limit range. From (26) the concentration of phosphate in the ash added to the 5 % cement is calculated.

$$c_{\rm P} = \frac{m_{\rm P}}{M_{\rm P} \cdot V_{\rm liquid}} = \frac{22.5 \text{ g} \cdot 0.0697}{115.02 \frac{\text{g}}{\text{mol}} \cdot 0.225 \text{ L}} = \frac{1.57 \text{ g}}{115.02 \frac{\text{g}}{\text{mol}} \cdot 0.225 \text{ L}} = 0.06 \frac{\text{mol}}{\text{L}}$$
(26)

As seen from (26) the actual concentration of phosphate does not exceed the lower boundary of the limit range, which means that the phosphate content in the added ash has no impact on the early age strength of the mortar. This is seen visually from Figure 24 and 25, where the strength of the 0.10 M mix has the same strength as the mix with DM water.

7.8 Setting time and hardening

7.8.1 Preliminary part

The setting time for mortar samples with respectively 5 % cement and 10 % sand along with a REF is determined by using the Vicatronic apparatus. The results are shown below in Figure 26.



Figure 26: Setting time

Figure 26 shows how far into the sample the needle reaches over time. This means, that the value on the *y*-axis actually represents the distance of the needle from the preset zero (bottom of container). As time goes, the mortar sets and the distance between needle and zero gets bigger, since the needle can no longer penetrate the mortar in the same degree as previously. The mortar can be said to have set, when the penetration value begins to converge towards a constant value.

For the REF this point is reached after approx 250 minutes, after approx 260 minutes for the 5 % cement and after approx 350 minutes for the 10 % sand. The small bumps appearing on the graphs after the setting are due to the surface of the hardened mortar not being completely plane, but rather uneven.

The reason why the 10 % sand has a longer setting time, can be explained by the extra 25 g of water added to the mixture, as declared in Table 2. It could also be explained by the addition of sludge ash, because the ash might hinder the water in getting to the cement particles, and thereby delaying the hydration and ultimately the setting.

The REF and the 5 % cement set approx with the same pace, which can be caused by the fact that there has not been added as much ash to the 5 % cement for it to be able to obstruct the water as it could be the case for the 10 % sand.

7.8.2 Further part

Below in Figure 27 the setting progressions of a REF, mixed with 0.10 M, 0.25 M, 0.50 M and 1.00 M concentrations of $NH_4H_2PO_4$ instead of water, are shown.



Figure 27: REF setting time with 0.10 M, 0.25 M, 0.50 M and 1.00 M ADP-concentrations

The plot shows an almost instant setting of the high concentration mixture (1.00 M), whereas the 0.1 M, 0.25 M and 0.50 M samples have more of a regular setting progress, with the 0.50 M sample setting after 550 minutes and thereby being delayed by approx 140 minutes relative to the 0.25 M, which sets after approx 410 minutes. The 0.25 M is delayed approx 10 minutes relative to the 0.10 M, due to a setting time of approx 400 minutes for the 0.10 M. The reason for the significant delay between 0.10 M and 0.25 M and the 0.50 M could be the extra amount of water added to the 0.50 M mortar (see Table 3). The extra water is added in order to obtain an acceptable degree of workability.

Because the setting of the 0.25 M mix is so close to the 0.10 M mix compared to how close it is to the 0.50 M, it could seem as if the coherence between concentration and setting time does not follow a linear progress, but rather a somewhat exponential one. However, all in all the order of the mixes in terms of setting is almost as expected. The only unexpected parameter within these results is the 1.00 M mix that sets immediately, and which from a rational point of view should have had the longest setting time. The immediate setting of the 1.00 M mix could be the result of a fast exhaustion of the water during the hydration process. Accordingly, the water content of the 1.00 M mix is probably not high enough relative to the phosphate content.

Next, in Figure 28, the setting times of a 5 % cement mortar mixed with the same concentrations as mentioned for the REF, are shown.



Figure 28: 5 % cement setting time with 0.10 M, 0.25 M, 0.50 M and 1.00 M ADP-concentrations

Figure 28 shows almost the same setting progress as for the REF in Figure 27. The 1.00 M mix sets extremely fast, which happens after the first 7 minutes. The quick setting of the 1.00 M mix can be due to the mentioned ratio between the water and dissolved phosphate and thereby exhaustion of the water, causing the mortar to set very fast.

The 0.10 M sets after approx 300 minutes which is about the same as the REF. The REF sets slightly slower though, which can be explained by the addition of ash to the 5 % cement mix, because the ash dries out the mortar in some degree, causing the mortar to set faster. On the contrary, the REF has more water available for hydration, making it workable for a slightly longer period.

Compared to settings of the REF, the 0.25 M and 0.50 M for the 5 % cement do not have the same visible difference in their setting times. The clustering of the settings show the same behavior as of the compressive strength, where the 0.10 M, 0.25 M and 0.50 M have approx the same strength after 5 days. The 5 days strength and the setting however do not have any direct link between them. It is also still clear from Figure 28 that the 0.10 M sets before both the 0.25 M and 0.50 M, which is also the case for the REF.

Both for the REF and the 5 % cement it stands clear, that the setting time is affected by the addition of the phosphate. If the mixes with added phosphate solutions are compared to the setting times from preliminary testing, it is seen, that the tendencies of the further part are similar to the slowest setting time of the preliminary part. Both the REF and the 5 % cement from the initial testing have setting times of about 250 minutes, whereas the lowest setting time for both the REF and 5 % cement with added phosphate is at least 300 minutes, when the 1.00 M mixes are not taken into account. All in all the phosphate clearly has a negative impact on the mortar in the early age.

Furthermore, a hypothesis regarding the instant setting of the 1.00 M mixes is put forward. The hypoth-

esis at hand concerns whether or not the immediate setting is due to actual setting as a result of chemical reactions between cement and water or if it is a question of the mortar drying out and stiffening. One could reason that the addition of the phosphate salt could exhaust or occupy the available water. This would cause the mortar to dry out and stiffen, and stop the intended hydration process. Whether or not this is the case is not known, but it should be examined how much water is shackled by the phosphate and how much is actually available for hydration. This has some importance to it, since it is only the water which reacts with cement that should be accounted for in the determination of the w/c-ratio.

In Figure 29 a comparison between 0.10 M and 1.00 M mixes are shown for REF and 5 % cement.





(a) 0.10 M mix (left) and 1.00 M mix (right)
(b) 0.10 M mix (left) and 1.00 M mix (right)
Figure 29: Comparison of 0.10 M and 1.00 M mixes for REF (29a) and 5 % cement (29b)

From both Figure 29a and 29b it is seen how the penetration of the mortar has stopped early for the 1.00 M mix, compared to the 0.10 M mix, where a lot more penetration holes from the probe are present.

8 Conclusion

8.1 Preliminary part

8.1.1 Ash characteristics

The initial purpose of the project was to test the use of sludge ash from Lynettefællesskabet I/S as a sand and cement replacement. During the preliminary part several tests were conducted on the ash in order to survey its chemical and physical characteristics, for instance by measuring its conductivity and grain size distribution. As a result of the characterisation, Table 18 and Table 19 were procured. They show the characteristic values of the ash.

Test	Value
pH [-]	11.8
Water content $[\%]$	0.078
LOI [%]	0.00
Solubility [%]	3.2
Water soluble anions	
Cl- [%]	0.02
NO ₃ - [%]	0.0007
SO_4^{2-} [%]	1.27
Conductivity $\left[\frac{mS}{cm}\right]$	3.27

Table 18: Ash characteristics I

Table 18 shows a solubility in water of 3.2 % for the ash, which correlates to the content of water soluble anions. The content of water soluble anions constitutes approx half of the total solubility, which could be expected, due to the fact that the other half is made up by the water soluble cations. The conductivity of 3.27 $\frac{\text{mS}}{\text{cm}}$, which has a direct link to the solubility, has been compared to other measurements from a project executed in 2013 by Morten Reiff et al (2013) [40]. The comparison showed a slight inconsistence in terms of where the ash has been extracted from, since the ash from the 2013 project has a conductivity of 7.81 $\frac{\text{mS}}{\text{cm}}$ coming directly from the furnace, whereas the ash subjected in this project has a conductivity less than half the previous (3.27 $\frac{\text{mS}}{\text{cm}}$). On the other hand, the conductivity for the stored ash in the 2013 project is 5.59 $\frac{\text{mS}}{\text{cm}}$ equaling the present value better, since the reduction can be explained by leaching of water soluble ions.

Test	Value $[\%]$
Heavy metals	
As	0.0001
Cd	0.0003
Cr	0.01
Cu	0.06
Ni	0.002
Pb	0.003
Zn	0.36
Macro elements	
Al	1.95
Mg	1.19
Na	0.48
Κ	1.05
Р	9.38

Table	19:	Ash	characteristics	Π
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Table 19 shows the content of heavy metals and macro elements. Concerning the heavy metals, the amount of cadmium, copper and zinc exceed the threshold values (see Table 4). The rest of the heavy metals are within the acceptable boundaries. For the macros, the alkali content (Na and K) and the content of Mg are within the limits of 5 % and 4 % respectively. The phosphate however exceeds the limit value of 5 % with its 9.38 %.

8.1.2 Capillary suction

By testing the capillary suction for 5 % cement and 10 % sand, it was found that for the 5 % cement, the capillary suction was the same for the 5c14d, 5c28d and REF28d, where it was higher for the 5c7d. This is due to the formation of hydration product in the more aged specimens, whereas the early age specimen still had a somewhat high pore content. For the 10 % sand the 10s7d, 10s14d and REF28d had a higher capillary suction than 10s28d, which is due to the amount of ash added to the mix. When more ash is added, more of the pores are filled out and the capillary suction lowers.

8.1.3 Porosity and density

The test of the porosity of 5 % cement and 10 % sand showed that the porosity of the 5 % cement was lower than the 10 % sand, due to a lower w/c-ratio. This tendency was present after 7, 14 and 28 days. The REF had a lower porosity than both the 5 % cement and 10 % sand after 28 days, because of an even lower w/c-ratio than the 5 % cement.

The density of the two different mixes turned out to be as expected, since the 5 % cement had the highest one. This is explained by the fact that the amount of ash added to the 10 % sand weighs less than the amount of sand replaced. Accordingly, the 5 % cement consists of more sand than the 10 % sand resulting in a higher density.

8.1.4 Compressive strength

After 1 day the REF, 5 % cement and 10 % sand have approx the same strengths which are 20.2 MPa, 20.1 MPa and 19.7 MPa respectively. Then after 3 days the REF and the 10 % sand have followed

approxiantely the same progress, resulting in strengths of 40.7 MPa and 39.0 MPa respectively. The 5 % cement on the other hand has a slightly lower strength with 36.7 MPa. After 5 days all three specimens have increased their strengths to 45.9 MPa for the REF, 43.1 MPa for the 10 % sand and 38.5 MPa for the 5 % cement.

This shows, that the REF gains the highest strength in the early age, which is caused by the removal of cement and thereby lowering the amount of hydration product for the 5 % cement. The reason for the lower strength of the 10 % sand is the fact that the ash packs itself around the cement particles causing a reduced flow of water and ultimately a delay of the hydration process and thereby strength development.

8.1.5 Setting time and hardening

The results of the Vicat test showed, that the REF and the 5 % cement sets approx at the same time, which is after 250-260 minutes. The setting for the 10 % sand steps in after approx 350 minutes, which can be caused by adding an additional 25 g of water in order to maintain sufficient workability. Another reason for the slower setting of the 10 % sand mix can, as for the compressive strength, be due to the packing of the ash around the cement particles, probably slowing down the hydration process and stiffening of the mortar.

8.2 Further part

As seen from Table 19 the phoshate content constitutes 9.38 % of the ash, which came to make up the mark off of the further part of the project. The impact of phosphate on the compressive strength of concrete was tested through a series of strength tests of mortar containing different concentrations of a $\rm NH_4H_2PO_4$ -solution.

8.2.1 Phosphate solubility

In order to imitate real life circumstances, it was tested by ICP-OES, how much of the phosphate in the sludge ash was soluble in base, since the mortarmix is highly alkaline. The result was, that when dissolved in NaOH, 74.28 % of the total amount of phosphate (93,794 $\frac{\text{mg}}{\text{kg}}$) was soluble corresponding to 6.97 % of the ash.

8.2.2 Compressive strength

The results of the compression tests of the REF with different concentrations of ADP show that the phosphate from the 0.10 M solution has almost no impact on the strength, whereas the effects are clear for the 0.25 M, 0.50 M and 1.00 M and that being negative effects. It is seen, that the strengths of the specimens are reversed proportional to the concentration of $NH_4H_2PO_4$, i.e. the higher the concentration, the lower the strength. This does not apply to the 0.10 M though, which has a slightly higher strength after 5 days than the specimen with demineralised water. This however is not seen upon as a definitive result, since it would entail a positive effect of the phosphate.

The compressive strengths of the 5 % cement with added ADP have approx the same progress as for the REF, meaning that the DM water, 0.10 M and 0.25 M have the highest strengths and the 0.50 M and 1.00 M have significantly lower strengths. In this case though, the three first mentioned concentrations

have almost attained the same strengths after 5 days, which redefines the threshold range of 0.10-0.25 M from the REF to 0.10-0.50 M from the 5 % cement.

With a limit range for the phosphate content, it was relevant to investigate the actual concentration of phosphate in the 5 % cement mortar mix. This concentration was found to be 0.06 M, which is lower than the 0.10 M from which there was no effect to be observed. It is thereby concluded, that the amount of phosphate in the sludge ash added to the 5 % cement has no visible effect in terms of compressive strength within the first 5 days of the concrete's service life.

8.2.3 Setting time and hardening

The setting of the REF with the four different ADP-solutions happens in the following order: 1.00 M, 0.10 M, 0.25 M and 0.50 M. Other than the 1.00 M mix, the order makes good sense, since a higher concentration of phosphate gives a longer setting time according to the tests. The 1.00 M mix however sets immediately (after 7 minutes), which was quite unexpected. 0.10 M sets after approx 400 minutes, 0.25 M sets after 410 minutes and the 0.50 M sets rather inconsequently, but after approx 550 minutes.

As for the REF, the 5 % cement with 1.00 M has set after 7 minutes, which yet again is unexpected, compared to the setting of the other concentrations. For the other three concentrations, the progressions are somewhat clustered together, but after closer inspection the 0.10 M sets after 300 minutes, the 0.25 M after 420 minutes and the 0.50 M after 450 minutes.

A hypothesis was put forward, concerning the question of whether the quick setting of the 1.00 M mixes is in fact a result of the mortar drying out, due to the high phosphate content rather than proper hydration and setting of the mortar.

9 Further work

Sludge ash today does not have a precise definition as a product. There are differences from each wastewater treatment plant in e.g. the burning process and temperature and therefore it has to be presumed that there is a difference from ash to ash. Furthermore, it is presumed there will be variations in the composition of the ash according to the time of the year.

Today it is cf. DS 2426 only allowed to add sludge ash as a type II-addition to concrete if the sludge ash is delivered with a declaration which meet some of the required chemical parameters as seen in DS 450-1 for fly ash. The ultimate objective in the future must be to have a DS for sludge ash as seen for fly ash (DS 450-1). Therefore, there has to be outlined some standards for use of the ash in concrete (composition and characteristics) according to different environmental requirements.

When adding sludge ash, the texture, use and production properties of the concrete have to be preliminarily tested cf. DS 2426 [44]. The preliminary test documents among others the strength of the concrete. Only the compressive strength is tested while it is presumed there is a clear connection with the tensile strength and stiffness. Furthermore, either a pore structure analysis or an accelerated testing for frost resistance has to be conducted.

To create confidence in a new kind of concrete more experiments and tests have to be conducted than the compulsory preliminary tests. From [14] an extended test is proposed:

- Tensile strength and elastic modulus
- Stress-strain curve
- Curing
- Mechanical characteristics in case of fire
- Carbonating
- Resisting potential of chloride
- Pore structure analysis and accelerated testing for frost resistance (both methods)
- Penetration of chloride
- Variation of conductivity

When using the sludge ash as a way to improve the environment it is of great importance to document this environmental improvement. The documentation has to secure that new environmental problems are not introduced when using sludge as a part-substitute of cement in concrete compared to traditional concrete. A life cycle assessment has to be conducted and included in the documentation.

This project focused on the impact on the compressive strength development of phosphate in the early phase. The long-acting impact of phosphate to concrete is still not known which would be interesting to study. In connection with this the next step would be to conduct more experiments in full-size-scale when using sludge ash.

There has to be more studies on the psychological impact on the reddish color the concrete gets when adding sludge ash. Today the reddish color is seen as a downside. Earlier projects, as the Grøn betonproject and the Biocrete-project, which also worked on incorporating sludge ash in concrete, both stopped because of, among others, the reddish color. The red color caused a very low commercial potential when it was only used in foundations and other things covered by soil [2]. It has to be examined where there is market for the reddish colored concrete.

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Appendices

A Mixing procedure for cement mortar cf. DS/EN 196-1

Mixing of the cement mortar has been given certain standards, which will be punctually outlined below for the reference mortar. Figure 30 shows the Hobart mixer utilised for mixing the mortar.



Figure 30: Hobart mixer [16]

Mixing of mortar [42]:

- 1. Weigh off 450.00 g of cement in the mixing bowl.
- 2. Weigh off 1350.00 g of sand.
- 3. Weigh off 225.00 g of water.
- 4. Start the mixer at low speed to break possible lumps.
- 5. Pour in the water, start the clock and let it mix for 30 seconds.
- 6. Pour in the sand steadily during 30 seconds.
- 7. Switch the mixer to high speed and mix for 30 seconds.
- 8. Stop the mixer for 90 seconds and scoop the remainings from the sides into the bowl within the first 30 seconds.
- 9. Start the mixer at high speed, let it mix for 60 seconds and the mixing is done.

Moulding of test specimen [42]:

- 1. Place the mould consisting of three 40 mm x 40 mm x 160 mm voids on the vibration table.
- 2. Fill the voids halfway with mortar.
- 3. Start the vibration table at 60 jolts for 30 seconds.
- 4. Stop the table and fill up the second half of the voids, ensuring an excess of mortar.

5. Start the table again for 30 seconds and surface the moulds using the surface planer within the 30 seconds.

Conditioning of test specimen [42]:

- 1. Place the moulds on a horizontal base in a moist air room.
- 2. Cover the face of the moulds with plastic and let it set overnight, before demoulding.
- 3. Demould with care for tests at ages greater than 24 h and place in water at 20 $^{\circ}\mathrm{C}$ in containers.
- 4. Remove specimen prisms required for testing not more than 15 min before the test is carried out.

Testing procedure [42]:

- 1. Place each prism half in the testing machine (verified in accordance with EN ISO 7500-1) for determination of the compressive strength.
- 2. Increase load smoothly at a rate of 2400 $\frac{N}{s}$ until fracture
- 3. Calculate the compressive strength $R_{\rm s}$ in MPa from $R_{\rm s} = \frac{F_{\rm c}}{1600}$

B Flow of hydraulic cement mortar cf. ASTM C1437-07

Determination of flow of hydraulic cement mortar has been given certain standards, which will be punctually outlined below.

Determination of flow [18]:

- 1. Mixing of mortar as described in Appendix A:
- 2. Wipe flow table clean and dry and place the flow mold at the center.
- 3. Fill half the mold with mortar and tamp (with sufficient pressure) 20 times with the tamper.
- 4. Fill the mold and tamp 20 times before cutting off the mortar to a plane surface.
- 5. Wipe the table top clean and dry and be careful to remove any water from around the flow mold.
- 6. Lift the mold away from the the mortar 1 min after completing the mixing operation.
- 7. Immediately drop the table 25 times in 15 s.
- 8. Measure the diameter of the mortar.

C Addition of ammonium dihydrogen phosphate (ADP)

Ammonium dihydrogen phosphate (ADP) has the chemical formula $NH_4H_2PO_4$. Table 20 below is used to determine the molecular mass of ADP with additional use of (27).

$$M_{\rm NH_4H_2PO_4} = M_{\rm N} + 6 \cdot M_{\rm H} + M_{\rm P} + 4 \cdot M_{\rm O} \tag{27}$$

Atom	Stoich. coeff.	$M\left[\frac{\mathrm{g}}{\mathrm{mol}}\right]$	Total $\left[\frac{g}{mol}\right]$
Ν	1	14.01	14.01
Η	6	1.01	6.06
Р	1	30.97	30.97
Ο	4	16.00	64.00
Total			115.04

Table 20: Molecular mass of ADP

Table 20 shows that the molecular mass of ADP is 115.04 $\frac{g}{mol}$.

Table 21 below shows how much ADP needs to be added for each concentration.

Table 21: Concentration and mass of ADP

$c \left[\frac{\mathrm{mol}}{\mathrm{L}}\right]$	V [L]	$m_{NH_4H_2PO_4}$ [g]
0.10	0.225	2.59
0.25	0.225	6.47
0.50	0.225	12.94
1.00	0.225	25.88
Total		41.41

The needed mass of $NH_4H_2PO_4$ for each mixture is calculated from fixed concentrations and volumes using (28).

$$m_{NH_4H_2PO_4} = M_{NH_4H_2PO_4} \cdot c \cdot V \tag{28}$$

D Ash characteristics

D.1 pH-determination

Princip

Jordens pH måles potentiometrisk i en opslemning af jord og kaliumchlorid i forholdet 1:2,5

Specielt apparatur

Til målingen benyttes kombinationsselektrode i forbindelse med et pH-meter, der tillader en nøjagtighed på $0.05~\mathrm{pH}\text{-enheder}.$

Kemikalie sikkerhed

Kaliumchlorid - Der foreligger ikke information, der gør det muligt at klassificere stoffet. Bruges med omtanke. Læs kemikaliebrugsanvisningen før arbejdet begynder.

Reagenser

- 1. Kaliumchlorid 1 M KCl: 74,56 g KCl afvejes på teknisk vægt og opløses i destilleret vand i en 1000,00 mL målekolbe.
- 2. Bufferopløsning, pH 4,01: Radiometer pH 4.
- 3. Bufferopløsning, pH 7,00: Radiometer pH 7.

Analysens udførelse

1. Fremstilling af jordopslemming:

5,00 g tør, knust jord afvejes på teknisk vægt i en 20 mL plastvials. Der tilsættes 12,5 mL 1 M KCl-opløsning med pipette. Opslemningen stilles på rystebord i 1 time, hvorefter jorden bundfældes i 5-10 minutter, indtil en væskefase har udskilt sig over jorden.

2. Målingens udførelse:

Elektroden anbringes i den øvre kolloidfattige del af opslemningen således at diafragmaet er under væskeoverfladen (under måling skal gummiproppen være aftaget). Undgå at elektroden ikke rammer jorden. Forud for hver måling skylles elektroden grundigt med destilleret vand, hvorefter en evt. dråbe aftørres forsigtigt med et stykke papir.

Beregning af resultat

Resultatet aflæses direkte på apparatet og angives som pH (KCl) med en decimal. Aflæsningen anses for stabil når der står "STAB" på displayet.

Affaldshåndtering

Kaliumchlorid og Metrohm pH 4 og pH 7 hældes i vasken. Plastvial med jorden/KCl skal opsamles i beholder til jordaffald.

D.2 Water content

Princip

I forbindelse med den elektrodialytisk jordrensning har jordens vandindhold stor betydning, da den elektriske strøm ledes gennem jorden via jordvæsken. Er vandindholdet i jorden mindre end ca. 15 %, er det nødvendigt for forsøgets gennemførelse at tilføre jorden ekstra væske.

Specielt apparatur

Til analysen benyttes et varmeskab.

Analysens udførelse

1. Ved præcis måling:

3 bægerglas stilles i varmeskab ved 105 °C natten over. Bægerglassene stilles til afkøling i eksikator og vejes på analysevægt (Dette gøres ved en tang da fingrene afsætter fugt).

Der afvejes 5 g jord i hvert bægerglas og prøverne tørres ved $105 \,^{\circ}\text{C}$ i varmeskab. Bægerglassene med den tørrede jord vejes på analyse vægt efter afkøling i eksikator.

2. Ved mindre præcis måling (mest anvendt):

3 bægerglas afvejes på teknisk vægt. Der overføres en vis mængde til hvert bægerglas, som igen vejes på teknisk vægt. Bægerglassene stilles i varmeskab natten over ved 105 °C. Bægerglassene med den tørrede jord vejes efter afkøling på teknisk vægt.

Beregning af resultat

Vandindholdet angives i procent af vægten af den fugtige jord.

%
vandindhold = $\frac{m_{\rm våd} - m_{\rm tør}}{m_{\rm våd}} \cdot 100$

Affaldshåndtering

Jorden skal opsamles i beholder til jordaffald og bægerglassene rengøres.

D.3 Loss on ignition

Princip

Jordens indhold af organisk materiale svarer stort set til det opnåede glødetab ved 550 °C. I en tungmetalforurenet jord vil tungmetallerne i høj grad reagere med det organiske materiale i jorden og sidder bundet i denne fraktion.

Specielt apparatur

Til analysen benyttes en muffelovn.

Analysens udførelse 3 digler sættes i muffelovn, som er opvarmet til 550 °C, hvor de står i 30 minutter (1 time hvis ovnen er kold). Diglerne afkøles i ekssikator og vejes på analyse vægt (diglerne transporteres med tang, da fingrene afsætter fugt og derved ændrer vægten). Derefter afvejes omkring 2,5 g tør, knust jord på analysevægt til hver digel. Diglerne med den tørre jord stilles i en opvarmet muffelovn og glødes ved 550 °C i 1 time. Diglerne med den glødede jord afkøles i ekssikator og vejes på analyse vægt.

Beregning af resultat

Glødetabet, som nogenlunde svarer til prøvens indhold af organisk stof, angives i procent af tørstofindholdet.

%glødetab = $\frac{m_{\text{muffelovn}} - m_{\text{efter muffelovn}}}{m_{\text{før muffelovn}}} \cdot 100$

Affaldshåndtering

Jorden skal opsamles i beholder til jordaffald.

D.4 Solubility in water

Analyse

- 1. 100,00 g tørret aske afvejes på teknisk vægt til en 1L plastikflaske med låg. Der tilsættes 500 mL destilleret vand. Prøven rystes og henstilles til bundfældning.
- 2. Et filterpapir vejes og sættes i en tragt over et måleglas.
- 3. Væsken hældes over i filterpapiret. Der tilsættes igen 500 mL destilleret vand til asken og prøven omrystes og henstilles.
- 4. Væsken hældes over i det samme filter og der tilsættes igen 500 mL destilleret vand til asken og prøven omrystes.
- 5. Hele prøven hældes over i filteret og stilles til afdrypning.
- 6. Når asken er næste tør stilles filteret med asken i varmeskab ved 105 °C natten over.
- 7. Asken og filteret vejes og vægten noteres.

D.5 Conductivity

Princip

En jordvæskes indhold af ioner og opløste forbindelser er af stor interesse, da dette kan give et billede af en jordvæskes samlede koncentration (ionstyrke), ionernes aktivitetsforhold i væsken samt give et indtryk af ligevægtsforholdene mellem faste bestanddele og opløste forbindelser. Ledningsevnen for en jordvæske er et udtryk for, hvor godt en elektrisk strøm kan ledes gennem den givne væske og den afhænger af, hvor mange lede partikler, der er til stede i væsken.

Specielt apparatur

Til målingen benyttes ledningsevnemåler.

Analysens udførelse

10,00 g tør knust jord afvejes på teknisk vægt til en 50 mL plastikflaske. Der tilsættes 25,00 mL destilleret vand med fuldpipette. Plastikflaskerne stilles ca. 30 minutter på rysteapparat, hvorefter jorden bundfældes i ca. 20 minutter, indtil en væskefase har udskilt sig over jorden.

Ledningsevneelektroden skylles med destilleret vand. Sæt elektroden ned i væske og der trykkes på "SAMPLE". Når displayet viser "STAB" tryk på "PRINT" og aflæs resultatet.

Beregning af resultat

På baggrund af ledningsevnemålingen beregnes jordens ionindhold i jordvæsken. Det samlede ionindhold i jordvæsken:

$$S_{\text{væske}}[\frac{\text{mækv.}}{\text{L}}] = \frac{10\text{cm}\cdot\text{mækv.}\cdot\text{ledningsevnen}[\frac{\text{mS}}{\text{cm}}]}{\text{L}\cdot\text{mS}}$$

Det samlede ionindhold i jordvæsken kan omregnes til et samlet ionindhold af ioner pr.

$$S_{\text{jord}} = \frac{S_{\text{væske}} \cdot V_{\text{vandtilsat}}}{M_{\text{jord}}}$$

Affaldshåndtering

Ekstrakerne hældes i affaldsdunk mærket X 4.41 (tungmetaller).

D.6 Water-soluble anions

Analyse

- 1. 10 g tørret aske afvejes på teknisk vægt til 100 mL plastikflaske. Der tilsættes 50 mL destilleret vand.
- 2. Prøven stilles på rystebord natten over.
- 3. Prøven filtreres med sprøjtefilter og prøven gemmes til ionchromotograf og AAS

D.7 Destruction of ash cf. DS 259

Princip

Denne oplukningsmetode er en Dansk Standard (DS 259) til bestemmelse af syreopløselige metaller i jorden. Metalkoncentrationen fundet ved denne metode svarer til en "total-koncentration" af det pågældende metal i jorden. Ved en fuldstændig destruktion af jorden, vil man dog have mulighed for at finde en højere værdi af de forskellige metaller, så DS 259 giver derfor snarere et fastlagt niveau for en metalkoncentration, end en fuldstændig bestemmelse af metal-koncentrationen i jorden.

Specielt apparatur

Til målingen benyttes et atomabsorptionsspektrofotometer (AAS).

Kemikalie sikkerhed

Salpetersyre - Brandnærende; Ætsende; Brandfarlig ved kontakt med brandbare stoffer. Alvorlig ætsningsfare. Undgå indånding af dampe. Brug syrehandsker, plastikforklæder, sikkerhedsbriller og stinkskab ved afmåling.

Salpetersyre halv konc. (1:1) - Lokalirriterende; Irriterer øjnene og huden. Brug engangshandsker, sikkerhedsbriller og stinkskab ved afmåling. Læs kemikaliebrugsanvisningen før arbejdet begynder.

Reagenser

Salpetersyre halvkonc, (1:1) HNO₃: 500 mL koncentreret HNO₃ overføres med måleglas til en 1000,00 mL målekolbe som er halvt fyldt med destilleret vand. Der blandes godt og tilsættes vand til mærket. Efter blanding overføres opløsningen til en plastikflaske og mærkes.

Analysens udførelse

- 1. 1,00 g tør, knust jord afvejes på teknisk vægt i et pyrex-glas med skruelåg (autoklaveglas) og der tilsættes 20,00 mL halvkoncentreret HNO₃ med fuldpipette (skal foregå i stinkskab).
- 2. Autoklavflaskerne lukkes helt til, da HNO₃ ellers vil fordampe. Flaskerne stilles i autoklaven ved 200 kPa (550 °C) i 30 minutter. Flaskerne afkøles derefter til stuetemperatur.
- 3. Prøverne filtreres med sug gennem et 0,45 μ m filter i stinkskab. Brug engangshandsker. Autoklaveflasken skylles med 3 gange destilleret vand. Filtreret skal suge tør mellem hvert skyl.
- 4. Filtratet hældes i en 100,00 mL målekolbe og der tilsættes destilleret vand til mærket og blandes. Væsken hældes på en 20 mL plast-vials og gemmes til AAS.

Bestemmelse af metaller

Ekstraktens indhold af metaller måles ved AAS under benyttelse af de standarder som hører til de enkelte metaller.

Beregning af resultat

 $\rm På$ baggrund af standard kurverne beregnes jordens indhold af metaller angivet i mg/kg.

$$\left[\frac{\mathrm{mg}}{\mathrm{kg}}\right] = \frac{A \cdot 0,100 \mathrm{L} \cdot C}{B \cdot 10^{-3} \mathrm{\frac{kg}{g}}}$$

DTU Civil Engineering Department of Civil Engineering Hvor A = Ekstraktens metal koncentration $\left[\frac{mg}{L} = ppm.\right]$, B = Jord afvejet [g] og C = Fortyndingsfaktor.

Affaldshåndtering

Salpetersyre hældes i affaldsdunke mærket X 4.18. Ekstrakerne hældes i affaldsdunk mærket X 4.41 (tungmetaller). Filterpapiret bortkastes i skraldespanden i stinkskabet. Jorden skal opsamles i beholder til jordaffald.
E Instructions for use of sludge as h from Lynettefællesskabet $\rm I/S$

Lynettefællesskabet I/S Toxido

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ARBEJDSPLADSBRUGSANVISNING

Flyveaske

dentifikation af stoffet/materialet					
PR-nummer:	Internt navn:	Flyveaske			
Dato sikkerhedsdatablad: ^{29.09.2011}	Leverandør:	Lynettefællesskabet I/S, Refshalevej 250, DK-1432 København K Tlf.: +45 3257 3232			
Brunnenteda 100 starstaferligendighet					

Oplysninger om regu	lering
Ætxende	
Farebetegnelse:	Ætsende
Faresymboler:	C
Indeholder:	Siliciumdioxid, phosphorpentaoxid, Calciumoxid, Jern(III)Oxide, Aluminiumoxid, chlor
R-sætninger:	R35 Alvorlig ætsningsfare.
S-sætninger:	S36/37/39 Brug særligt arbejdstøj, egnede beskyttelseshandsker og -briller/ansigtsskærm. S63 Ved ulykkestilfælde ved indånding bringes tilskadekomne ud i frisk luft og holdes i ro. S26 Kommer stoffet i øjnene, skylles straks grundigt med vand og læge kontaktes.
Kodenummer:	
Anden mærkning:	
Anvendelses- begrænsninger:	Unge under 18 år må ikke erhvervsmæssigt anvende eller udsættes for produktet. Unge over 15 år er dog undtaget denne regel, hvis produktet indgår som et nødvendigt led i en uddannelse.
Krav om uddannelse:	Ingen særlig uddannelse er nødvendig, men et grundigt kendskab til denne brugsanvisning eller et sikkerhedsdatablad bør være en forudsætning.

Fareidentifikation

С

Yderligere information: Alvorlig ætsningsfare.

Sundhedsfarlige egenskaber			
Indånding:	Indånding af støv virker ætsende på de øvre luftveje. Giver svie i næse, mund og svælg, samt nysen, hoste åndedrætsbesvær og brystsmerter.		
Indtagelse:	Indtagelse kan fremkalde ætsninger i mund, spiserør og mavesæk, smerter i mund, svælg og mave, synkebesvær, ildebefindende og blodigt opkast. Brune pletter og ætssår kan ses i og omkring munden.		
Hudkontakt:	Virker ætsende og giver brændende smerte, rødme, blærer og ætssår ved hudkontakt.		
Øjenkontakt:	Øjenkontakt kan fremkalde dybe ætsninger, smerter, tåreflåd og kramper i øjenlågene. Risiko for alvorlig øjenskade med synstab.		
Overfølsomhed:	Testdata foreligger ikke.		
Langtidsvirkninger:	Testdata foreligger ikke.		

Personlige værnemidler

Forholdsregler ved brug: Åndedrætsværn:

Brug åndedrætsværn med P2 filter ved utilstrækkelig ventilation.

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Lynettefællesskabet I/S Toxido

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\bigcirc			
Ha be	indsker og skyttelsestøj:	A	nvend nitrilgummi handsker.
🍞 Øj	enværn:	В	rug beskyttelsesbriller.
Placering	af personlige		
Kontaktpe	erson:		
Førstehja	elpsforanstalt	ninger	See frick luft, skyl munden med vand og nyde næsen grundigt. Seg læge ved
P 7	Indånding:		vedvarende ubehag.
	Indtagelse:		Skyl munden grundigt og drik 1-2 glas vand i små slurke. Søg omgående læge.
	Hud:		Fjern forurenet tøj, ur og smykker. Vask huden med vand og sæbe. Søg omgående læge.
	Øjne:		Spil øjet godt op, fjern eventuelle kontaklinser og skyl straks med vand (helst fra øjenskyller) og søg omgående læge. Fortsæt skylningen til lægen overtager behandlingen.
	Forbrænding:		Ingen data tilgængelig
	Øvrige oplysni	inger:	Ved henvendelse til lægen medbringes denne brugsanvisning eller et sikkerhedsdatablad.
	Førstehjælpsu	dstyr:	Øjenskyl
	Nødtlf. nr:		
Håndteri	ng og opbeva	rina	
	Håndtering:		
	Opbevaringsst	ted:	Opbevares forsvarligt, utilgængeligt for børn og ikke sammen med levnedsmidler, foderstoffer, lægemidler o. lign. Bør opbevares i tæt tillukket originalemballage. Skal opbevares på et tørt, køligt og ventileret sted.
Brandbe	kæmpelse		
18	Brandbekæm	pelse:	Produktet er ikke umiddelbart antændeligt. Undgå indånding af dampe og røggasser - søg frisk luft.
<u>L</u> E	Slukningsudst	yr:	Sluk med pulver, skum, kulsyre eller vandtåge. Brug vand eller vandtåge til nedkøling af ikke antændt lager.
Forbolds	regler over fo	rudelin	ved ubeld
Forholds	regier over for	uusiip	
udslip ve	d uheld:		
Udstyr ud	Spild må ikke udledes til kloak og/eller overfladevand. Spild opfejes/opsamles til evt. Udstyr udslip/uheld: genbrug eller overføres til egnede affaldsbeholdere. Mindre spild tørres op med en fugt klud.		
Bortskaf	felse		
Bortskaffe	Jortskaffelse: Spild og affald samles i lukkede og tætte beholdere. Bortskaffes i overensstemmelse		affald samles i lukkede og tætte beholdere. Bortskaffes i overensstemmelse med ale regulativer.
Affaldsbeholder: EAK-kode: 19		EAK-kode	e: 19 01 13: Flyveaske indeholdende farlige stoffer.
Affaldsaft	ager:		
Miliconh	eninger		
willigobly	sninger		
Fysiske/	kemiske egens	skaber	
Lugt: Kara	kteristisk		

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Lynettefællesskabet I/S Toxido

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Udseende: Rødt fast stof/flager/granulat/pulver

Stabilitet og reaktivitet

Produktet er stabilt ved anvendelse efter leverandørens anvisninger.

Sammensætning-/oplysning om indholdsstoffer					
Cas nr.	Kemisk navn	W/W%	Klassificering	Grænseværdi	Noter
60676-86-0 1314-56-3 1305-78-8 1309-37-1 1344-28-1 7782-50-5	Siliciumdioxid phosphorpentaoxid Calciumoxid Jern(III)Oxide Aluminiumoxid chlor	25-35 20-25 10-15 10-15 5-10 <0,01	- C;R35 - - T;R23 Xi;R36/37/38 N;R50	0,1 (respirabel) mg/m3 () 1 mg/m3 (E) 2 mg/m3 () 3,5 (ber. som Fe) mg/m3 () 5 (ber. som Al) mg/m3 () 0,5 ppm 1,5 mg/m3 (F S)	

Transportoplysninger

ADR: UN: 3260, Ætsende surt uorganisk fast stof, N.O.S.(phosphorpentaoxid)

Andre oplysninger				
Bemærkninger:	Dette sikkerhedsdatablad er udarbejdet på baggrund af de oplysninger, leverandøren har kunnet levere om produktet ved udarbejdelsen (f.eks. datablade og lignende).			
Anvendelse:	Affaldsprodukt			
Må ikke bruges til:	Unge under 18 år må over 15 år er dog und uddannelse.	ikke erhvervsmæssigt anvende eller udsættes for produktet. Unge Itaget denne regel, hvis produktet indgår som et nødvendigt led i en		
Ordlyd af R-sætninger:	R35 Alvorlig ætsningsfare., R23 Giftig ved indånding., R36/37/38 Irriterer øjnene, åndedrætsorganerne og huden., R50 Meget giftig for organismer, der lever i vand.			
Udarbejdet af:	Toxido1/MUD/Lynette	efællesskabet Revideret af:		
Udarbejdet dato:	11-02-2014	Revideret dato:		
Udarbejdet af: T	M	Revideret af:		
Udarbejdet dato: 1	2-12-2011 00:00:00	Revideret dato:		

- MSDS - Flyveaske - Lynettefællesskabet IS - 29092011.pdf

http://lfnotes1/toxido/apbweb.nsf/ALL/174085D330C1B547C1257964005917BD?op... 11-02-2014

.

Sikkerhedsdatablad



Revision: 29-09-2011 Erstatter: 23-09-2011 Version: 01.01/DNK

PUNKT 1: Identifikation af stoffet/blandingen og af selskabet/virksomheden 1.1. Produktidentifikator Handelsnavn: Flyveaske

1.2. Relevante identificerede anvendelser for stoffet eller blandingen samt anvendelser, der frarådes Anbefalede anvendelser: Isoleringsmateriale, beton, cement.

Branche:	Industri generelt
1.3. Nærmere oplysninger	om leverandøren af sikkerhedsdatabladet
Leverandør:	Lynettefællesskabet I/S
	Refshalevei 250
	1432 København K
	Danmark
Tlf.:	+45 32573232
Fax:	+45 32543122
E-mail:	info@lvn-is.dk
Kontaktperson:	Tanja Mazur

1.4. Nødtelefon

82 12 12 12 (Giftlinien)

PUNKT 2: Fareidentifikation 2.1. Klassificering af stoffet eller blandingen DPD-klassificering: C;R35

Se punkt 16 for ordlyd af R- og H-sætninger.

Væsentligste skadevirkninger: Alvorlig ætsningsfare. Indtagelse kan fremkalde ætsninger i mund, spiserør og mavesæk. Smerter i mund, svælg og mave. Synkebesvær, ildebefindende og blodigt opkast. Brune pletter og ætssår kan ses i og omkring munden. Virker ætsende og giver brændende smerte, rødme, blærer og ætssår ved hudkontakt. Øjenkontakt kan fremkalde dybe ætsninger, smerter, tåreflåd og kramper i øjenlågene. Risiko for alvorlig øjenskade med synstab.

2.2. Mærkningselementer

1

ndeholder:		Phosph	orpentaoxid; Calciumoxid	
areangivelse:		Ætsend	le	
-sætninger:		Alvorlig	ætsningsfare.	
S-sætninger:		Komme Brug sa Ved uly etikette	er stoffet i øjnene, skylles straks grundigt med vand og læge kontaktes. erligt arbejdstøj, egnede beskyttelseshandsker og -briller/ansigtsskærm. kkestilfælde eller ved ildebefindende er omgående lægebehandling nødve n, hvis det er muligt.	endig, vis
nden mærkning	:	Ingen.		
.3. Andre farer				
		Vurder	ng for PBT og vPvB er ikke foretaget.	
UNKT 3: Samm	nensætnir	ig af/oplysning o	m indholdsstoffer	
egistrerings- CA	AS/	Stof	DSD-klassificering/ w/w%	Note
ummer EF	-nummer	Ciliaiumdiauid	CLP-klassificering	12
60	676-86-0	Siliciumdioxid	- 25-35	13
13	14-56-3	Phosphorpentaoxic	C;R35 20-25	12, 13
21	5-236-1 05-78-8	Calciumoxid	Xi; R36-R37-R41 10-15	13
21	5-138-9	1	Eye Damage 1; H318 Skin Imit 2; H315	
13	09-37-1	Jern(III)Oxid	- 10-15	13
21	5-168-2	·		5.
13	44-28-1	Aluminiumoxid	- 5-10	13
77	82-50-5	Chlor	T;R23 Xi;R36/37/38 N;R50 < 0,01	12, 13
23	1-959-5		Acute Tox. 3 *;H331 Eye Irrit. 2;H319	÷.
-			Aquatic Acute 1;H400	
 Stoffet er opta Stoffet har en 	aget på El national g	J's grænseværdili grænseværdi.	ste for erhvervsmæssig eksponering	
e punkt 16 for o	ordlyd af R	og H-sætninger.		
ðvrige oplysninge	er:	Produkt komplel vanadiu	et indeholder i varierende mængder i øvrigt: Svovl (svovltrioxid) samt diverse spore se forbindelser af blandt andet bly, cadmium, chrom, kobber, cobalt, mangan, nikk m, sølv, tin, thallium, kviksølv, arsen, antimon, molybdæn.	lementer af el, zink,
	ehjælpsfo	ranstaltninger		
PUNKT 4: Første		njælpsforanstalt	linger	edvarende
PUNKT 4: Første I.1. Beskrivelse ndånding:	af førstel	Søg fri ubehag	i. I.	
PUNKT 4: Første I.1. Beskrivelse ndånding: ndtagelse:	af førstel	Søg fri ubehag Skyl m omgåe	sk lunt, skyl munden med vand og puds næsen grundigt. Søg læge ved ve j. unden grundigt og drik 1-2 glas vand i små slurke. Fremkald ikke opkastn nde læge.	ing. Søg
PUNKT 4: Førsto I.1. Beskrivelse ndånding: ndtagelse: Hud:	af første	Søg fri ubehag Skyl m omgåe Fjern s omgåe	sk luft, skyl munden med vand og puds næsen grundigt. Søg læge ved ve j. unden grundigt og drik 1-2 glas vand i små slurke. Fremkald ikke opkastn nde læge. traks forurenet tøj, ur og smykker. Vask huden længe og grundigt med va nde læge.	ning. Søg Ind. Søg

J

Øvrige oplysninger:	Ved henvendelse til læge medbringes sikkerhedsdatablad eller etiket.
4.2. Vigtigste symptomer og virkni 4.3. Angivelse af om øjeblikkelig la	nger, både akutte og forsinkede Indtagelse kan fremkalde ætsninger i mund, spiserør og mavesæk. Smerter i mund, svælg og mave. Synkebesvær, ildebefindende og blodigt opkast. Brune pletter og ætssår kan ses i og omkring munden. Virker ætsende og giver brændende smerte, rødme, blærer og ætssår ved hudkontakt. Øjenkontakt kan fremkalde dybe ætsninger, smerter, tåreflåd og kramper i øjenlågene. Risiko for alvorlig øjenskade med synstab. ægehjælp og særlig behandling er nødvendig Behandl symptomer. Sørg for, at lægeligt personale er informeret om det anvendte materiale og tager forholdsregler til beskyttelse af dem selv.
PUNKT 5: Brandbekæmpelse	
5.1. Slukningsmidler Egnede slukningsmidler	Sluk med pulver, skum, kulsyre eller vandtåge. Brug vand eller vandtåge til nedkøling af ikke antændt lager.
Uegnede slukningsmidler	Brug ikke vandstråle, da det kan sprede branden.
5.2. Særlige farer i forbindelse me	d stoffet eller blandingen Produktet er ikke umiddelbart antændeligt. Undgå indånding af dampe og røggasser - søg frisk luft.
5.3. Anvisninger for brandmandsk	ab Hvis det kan gøres uden fare, fjernes beholdere fra det brandtruede område. Undgå indånding af dampe og røggasser - søg frisk luft. Slukningsvand, som har været i kontakt med produktet, kan være ætsende. Anvend luftforsynet åndedrætsværn og kemisk beskyttelsesdragt.
PUNKT 6: Forholdsregler over for 6.1. Personlige sikkerhedsforanst For ikke-indsatspersonel:	udslip ved uheld altninger, personlige værnemidler og nødprocedurer Stå i vindsiden/hold afstand til kilden. Brug beskyttelsesbriller ved risiko for støv i øjnene. Brug handsker. Ved utilstrækkelig ventilation skal der anvendes åndedrætsværn.
For indsatspersonel:	Udover ovenstående: Kemikalieindsatsdragt svarende til EN 943-2 anbefales.
6.2. Miljøbeskyttelsesforanstaltnir	i ger Spild må ikke udledes til kloak og/eller overfladevand.
6.3. Metoder og udstyr til inddæm	ning og oprensning Spild opfejes/opsamles til evt. genbrug eller overføres til egnede affaldsbeholdere. Mindre spild tørres op med en fugtig klud.
6.4. Henvisning til andre punkter	Se punkt 8 for værnemiddeltype. Se punkt 13 for bortskaffelse.
PUNKT 7: Håndtering og opbevari 7.1. Forholdsregler for sikker hån	ing dtering Alt arbejde skal foregå under effektiv ventilation. Vask hænder før pauser, toiletbesøg og efter endt arbejde. Undlad at spise, drikke eller ryge under arbejdet. Undgå kontakt med huden og øjnene. Der skal være adgang til rindende vand og øjenskyller. Der skal være adgang til nødbruser. Arbejde med produktet er ikke omfattet af Arbejdstilsynets bekendtgørelse om arbejde med kodenummererede produkter.
7.2. Betingelser for sikker opbeva	ring, herunder eventuel uforenelighed Opbevares forsvarligt, utilgængeligt for børn og ikke sammen med levnedsmidler, foderstoffer, lægemidler o.lign. Bør opbevares i tæt tillukket originalemballage. Skal opbevares på et tørt, køligt og ventileret sted.
7.3. Særlige anvendelser	Ingen.

PUNKT 8: Eksponeringskontrol/personlige værnemidler

7

8.1. Kontrolparametre

Grænseværdier Anmærkninger Indholdsstof Grænseværdi Calciumoxid 2 mg/m³ 3,5 (ber. som Fe) mg/m³ 1 mg/m³ Jern(III)Oxid Phosphorpentaoxid Aluminiumoxid 5 (ber. som Al) mg/m³ 0.1 (respirabel) mg/m³ Siliciumdioxid Chlor 0,5 ppm 1,5 mg/m³ S Retsgrundlag: Bekendtgørelse om grænseværdier for stoffer og materialer nr. 507/2011. E: Betyder at stoffet har en EF-grænseværdi S: Betyder at grænseværdien ikke bør overskrides. Værdien gælder for en eksponeringsperiode Anmærkninger på 15 minutter. Målemetoder: Overholdelse af de angivne grænseværdier kan kontrolleres ved arbejdshygiejniske målinger. 8.2. Eksponeringskontrol Egnede foranstaltninger til Brug værnemidler som angivet nedenfor. Se endvidere punkt 7.1. eksponeringskontrol: Brug beskyttelsesbriller ved risiko for støv i øjnene. Øjenværn skal følge EN 166. Personlige værnemidler, beskyttelse af øjne/ansigt: Brug beskyttelseshandsker af plast eller gummi Ved spild på handsken skiftes denne straks og Personlige værnemidler, hænderne vaskes med vand og sæbe. Handsker skal følge EN 374. beskyttelse af hud: Brug åndedrætsværn med P2 filter ved utilstrækkelig ventilation. Åndedrætsværn skal følge en Personlige værnemidler, af følgende standarder: EN 136/140/145. åndedrætsværn: Foranstaltninger til begrænsning af Det skal sikres at lokale regler for udledning overholdes. eksponering af miljøet:

PUNKT 9: Fysisk-kemiske egenskaber

9.1. Oplysninger om grundlæggende fysiske og kemiske egenskaber Tilstandsform: Fast stof/ Flager/ Granulat/ Pulver Farve: Brun/ Grå/ Sort Lugt: Karakteristisk Lugttærskel: pH (brugsopløsning): pH (koncentrat): Smeltepunkt/frysepunkt: Ingen data Ingen data Ingen data Ingen data Begyndelseskogepunkt og kogepunktsinterval: Flammepunkt: Ingen data Ingen data Fordampningshastighed: Antændelighed (fast stof, luftart): Ingen data Ingen data Øvre/nedre antændelsesgrænser: Øvre/nedre eksplosionsgrænser: Ingen data Ingen data Damptryk: Dampmassefylde: Ingen data Ingen data Relativ massefylde: Opløselighed: Ingen data Opløselighed i vand: Uopløselig Fordelingskoefficient Ingen data n-oktanol/vand: Selvantændelsestemperatur: Ikke selvantændeligt Dekomponeringstemperatur: Viskositet: Ingen data Ikke relevant. Eksplosive egenskaber: Oxiderende egenskaber: Ingen data Ingen data 9.2. Andre oplysninger

Ingen

)

PUNKT 10: Stabilitet og reaktivitet 10.1. Reaktivitet			
	Ingen data		
10.2. Kemisk stabilitet	Produktet er stabilt ved anvendelse efter leverandørens anvisninger.		
10.3. Risiko for farlige reaktioner	Ingen kendte.		
10.4. Forhold, der skal undgås	Ingen kendte.		
10.5. Materialer, der skal undgås	Ingen kendte.		
10.6. Farlige nedbrydningsprodukt	ter		
	Ingen kendte.		
PUNKT 11: Toksikologiske oplysn 11.1. Oplysninger om toksikologis	inger ke virkninger		
Akut toksicitet - oral:	Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke.		
Akut toksicitet - dermal:	Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke.		
Akut toksicitet - indånding:	Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke.		
Hudætsning/-irritation:	Virker ætsende og giver brændende smerte, rødme, blærer og ætssår ved hudkontakt. Testdata foreligger ikke.		

Alvorlig øjenskade/øjenirritation:	Øjenkontakt kan fremkalde dybe ætsninger, smerter, tåreflåd og kramper i øjenlågene. Risiko
	for alvorlig øjenskade med synstab. Testdata foreligger ikke.

Sensibilisering:	Produktet er ikke klassificeringspligtigt.	Testdata foreligger ikke.
------------------	--	---------------------------

Mutagenicitet: Produktet er ikke klassificeringspligtigt. Testdata foreligger ikl

Kræftfremkaldende egenskaber: Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke.

Reproduktionstoksicitet: Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke.

Indånding af støv virker ætsende på de øvre luftveje. Giver svie i næse, mund og svælg, samt nysen, hoste, åndedrætsbesvær og brystsmerter. Testdata foreligger ikke. Toksicitet ved en enkelt

Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke. Toksicitet ved gentagen eller

Aspirationsfare: Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke. Indtagelse kan fremkalde ætsninger i mund, spiserør og mavesæk. Smerter i mund, svælg og mave. Synkebesvær, ildebefindende og blodigt opkast. Brune pletter og ætssår kan ses i og omkring munden. Andre toksikologiske virkninger:

PUNKT 12: Miljøoplysninger

12.1. Toksicitet

langvarig eksponering:

eksponering:

Produktet er ikke klassificeringspligtigt. Testdata foreligger ikke.

12.2. Persistens og nedbrydelighed

Forventes ikke at være biologisk nedbrydeligt. Testdata foreligger ikke.

12.3. Bioakkumuleringspotentiale

1

Produktet indeholder mindst et stof, der kan bioakkumuleres i organismer. Testdata foreligger ikke.

12.4. Mobilitet i jord	Produktet forventes at have lav mobilitet i jord og sediment.
12.5. Resultater af PBT- og vPvB-	vurdering Vurdering er ikke foretaget.
12.6. Andre negative virkninger	Produktet vil lokalt ændre pH i vandmiljøet.
PUNKT 13: Forhold vedrørende b	ortskaffelse
	Undgå udslip til kloak eller overfladevand.
	Spild og affald samles i lukkede og tætte beholdere, der bortskaffes via den kommunale affaldsordning for farligt affald med nedenstående specifikationer.
	EAK-kode: Afhængigt af branche og anvendelse f.eks. 19 01 13 Flyveaske indeholdende farlige stoffer
PUNKT 14: Transportoplysninger ADR/RID	
14.1. UN-nummer	3260
14.2. UN-forsendelsesbetegnelse (UN proper shipping name)	ÆTSENDE SURT UORGANISK FAST STOF, N.O.S. (Phosphorpentaoxid)
-	
Farenummer	88
Tunnelrestriktionskode:	E
14.5. Miljøfarer	Produktet skal ikke mærkes som miljøfarligt (symbol: fisk og træ).
ADN	
14.1. UN-nummer	3260
14.2. UN-forsendelsesbetegnelse (UN proper shipping name)	CORROSIVE SOLID, ACIDIC, INORGANIC, N.O.S. (phosphorus pentoxide)
14.3. Transportfareklasse(r)	8
14.4. Emballagegrupper	I
14.5. Miljøfarer	Produktet skal ikke mærkes som miljøfarligt (symbol: fisk og træ).
Miljøfare i tankskibe:	
IMDG	
14.1. UN-nummer	3260
14.2. UN-forsendelsesbetegnelse (UN proper shipping name)	CORROSIVE SOLID, ACIDIC, INORGANIC, N.O.S. (phosphorus pentoxide)
14.5. Transportarekiasse(f)	0
14.4. Emballagegrupper	
14.5. Miljøfarer	Produktet er ikke Marine Pollutant (MP).
IMDG Code segregation group:	

....

1 - Acids ICAO/IATA 14.1. UN-nummer 3260 CORROSIVE SOLID, ACIDIC, INORGANIC, N.O.S. (phosphorus pentoxide) 14.2. UN-forsendelsesbetegnelse (UN proper shipping name) 8 14.3. Transportfareklasse(r) 14.4. Emballagegrupper 1 14.6. Særlige forsigtighedsregler for brugeren Ingen 14.7. Bulktransport i henhold til bilag II i MARPOL 73/78 og IBC-koden PUNKT 15: Oplysninger om regulering 15.1. Særlige bestemmelser/særlig lovgivning for stoffet eller blandingen med hensyn til sikkerhed, sundhed og miljø Særlige bestemmelser: Unge under 18 år må ikke erhvervsmæssigt anvende eller udsættes for produktet. Unge over 15 år er dog undtaget denne regel, hvis produktet indgår som et nødvendigt led i en uddannelse. 15.2. Kemikaliesikkerhedsvurdering Der er ikke udført kemikaliesikkerhedsvurdering PUNKT 16: Andre oplysninger Der er foretaget ændringer i følgende punkter: 16 PBT: Persistent, Bioaccumulative and Toxic vPvB: Very Persistent and Very Bioaccumulative STOT: Specific Target Organ Toxicity Forklaring til forkortelser: R-sætninger: R23 Giftig ved indånding. R35 Alvorlig ætsningsfare. R36 Irriterer øjnene. R36/37/38 Irriterer øjnene, åndedrætsorganerne og huden. R37 Irriterer åndedrætsorganerne. R41 Risiko for alvorlig øjenskade. R50 Meget giftig for organismer, der lever i vand. H314 Forårsager svære forbrændinger af huden og øjenskader. H315 Forårsager hudirritation. H318 Forårsager alvorlig øjenskade. H-sætninger: H319 Forårsager alvorlig øjenirritation. H331 Giftig ved indånding. H335 Kan forårsage irritation af luftvejene. H400 Meget giftig for vandlevende organismer. Uddannelse: Et grundigt kendskab til dette sikkerhedsdatablad bør være en forudsætning. Øvrige oplysninger: Lovgrundlag: Lovgrundlag: ADR 2011 udgave og IMDG 2010 udgave. Bekendtgørelse om klassificering, emballering, mærkning, salg og opbevaring af kemiske stoffer og produkter nr. 50/2011. Europa-Parlamentets og Rådets forordning (EF) nr. 1272/2008 af 16. december 2008 om klassificering, mærkning og emballering af stoffer og blandinger og om ændring og ophævelse af direktiv 67/548/EØF og 1999/45/EF og om ændring af forordning (EF) nr. 1907/2006 + Kommissionens forordning (EF) nr. 790/2009 af 10. august 2009 om ændring, med henblik på tilegespise til den tekniske og videnskabelige udvikliger af Europa-Parlamentets og Rådets

tilpasning til den tekniske og videnskabelige udvikling, af Europa-Parlamentets og Rådets

forordning (EF) nr. 1272/2008 om klassificering, mærkning og emballering af stoffer og blandinger (CLP). Bekendtgørelse om grænseværdier for stoffer og materialer nr. 507/2011. Bekendtgørelse om særlige pligter for fremstillere, leverandører og importører mv. af stoffer og materialer efter lov om arbejdsmiljø nr. 559/2002, senest ændret ved nr. 1252/2008 + Forordning 2006/1907/EF, senest ændret ved 2011/494/EU. (REACH) Miljøstyrelsens bekendtgørelse om affald nr. 224/2011. Arbejdstilsynets bekendtgørelse om unges arbejde, nr. 239/2005 senest ændret ved nr. 514/2011. Arbejdstilsynets bekendtgørelse om foranstaltninger til forebyggelse af kræftrisikoen ved arbejde med stoffer og materialer nr. 908/2005, senest ændret ved nr. 1175/2007. Bekendtgørelse om arbejde med stoffer og materialer nr. 292/2001, senest ændret ved nr. 20/2009.

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F Poster - Preliminary part

- Bearbejdelighed og hærdeforløb

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DTU Byg Institut for Byggeri og Anlæg



lennis Viborg Andersen I-mail: x112856%student.dta.dk NJ: 60182275



G Raw data

G.1 Preliminary part: ICP-OES

			ICP		
Stof	Enhed	Opløsning A	Opløsning B	Opløsning C	Gennemsnit
	mg/L	195,771000	197,704000	191,967000	195
Ai	mg/kg	19577	19770	19197	19515
٨с	mg/L	0,000000	0,018271	0,000000	0
AS	mg/kg	0	2	0	1
Cd	mg/L	0,028142	0,027067	0,025714	0
Cu	mg/kg	3	3	3	3
Cr	mg/L	0,534369	0,526305	0,522254	1
	mg/kg	53	53	52	53
Cu	mg/L	6,342710	<mark>6,315430</mark>	6,203160	6
Cu	mg/kg	634	632	620	629
Ni	mg/L	0,206328	0,172821	0,177584	0
	mg/kg	21	17	18	19
Ph	mg/L	1,313180	1,301120	1,299430	1
F D	mg/kg	131	130	130	130
Zn	mg/L	35,576000	35,888500	35,088400	36
211	mg/kg	3558	3589	3509	3552
Na	mg/L	48,330700	47,753800	47,545400	48
ING	mg/kg	4833	4775	4755	4788
ĸ	mg/L	108,893000	102,623000	103,055000	105
ĸ	mg/kg	10889	10262	10306	10486
Ph	mg/L	950,622000	949,207000	913,985000	938
10	mg/kg	95062	94921	91399	93794
Ма	mg/L	183,274000	181,868000	180,542000	182
ivig	mg/kg	18327	18187	18054	18189

Afvejet [g]	1
Tilsat [mL]	100

G.2 Preliminary part: IC

			IC		
Stof	Enhed	Opløsning A	Opløsning B	Opløsning C	Gennemsnit
A1	mg/L	31,0122	31,9608	32,4233	32
AI	mg/kg	155,0610	159,8041	162,1164	159
	mg/L	0,8017	1,5693	1,6961	1
AS	mg/kg	4,0083	7,8464	8,4807	7
Cd	mg/L	2550,7496	2555,9991	2514,4685	2540
	mg/kg	12753,7482	12779,9954	12572,3423	12702



G.3 Preliminary part: Grain size distribution



Malvem Instruments Ltd.

Malvem, UK Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789 Mastersizer 2000 Ver. 5.60 Serial Number : MAL1017217 File name: 140227-GrD-IK Record Number: 4 27-02-2014 11:10:24





Sample Na Gr-D-IK-B -	ame: Average			SOP Nan Flyveask	ne: easke vå	b		Measu 27. febi	r ed: ruar 2014 1	0:53:34			
Sample So Paris	ource & ty	ype:		Measure f-user	d by:			Analys 27. febr	ed: ruar 2014 1	0:53:36			
Sample bu 123-ABC	lk lot ref	:		Result Se Averaged	ource:								
Particle Na aske	ame:			Accesso Hydro 20	ry Name 00SM (A)	:		Analys Genera	is model: I purpose			Sensitivity Enhanced	<i>ı</i> :
Particle RI	:			Absorpti	ion:			Size ra	nge:			Obscurati	on:
1.500 Dispersant	t Name:			0 Dispersa	int RI:			0.020 Weight	to 20 ed Residu	100.000 Ial:	um	Result Em	。 ulation:
Water				1.330				0.454	%			Off	
Concentrat 0.0540	tion: %Vol			Span : 7.819				Uniforr 2.57	nity:			Result un Volume	its:
Specific Su 0.206	urface Ar m²/g	rea:		Surface \ 29.121	Weighted um	l Mean D[3,	2]:	Vol. We 256.614	eighted Me 4 um	ean D[4,3]:		
d(0.1):	11.219	um			d(0.5): 88.1	118 un	n			d(0.9):	700.226	um
		-			Pa	article Size	Distributi	on					
Volume (%)	4. 3. 2. 1. 0.	5 5 4 5 3 5 2 5 1 5 0 0							100	10		00	
		0.01	,	J.1	1	Douticlo C	10 (um)		100	10	00 30	00	
	Gr-D-IK-	B - Aver	age, 27. 1	februar 20:	14 10:53	3:34	nze (µm)						-
	Size (µm) 1 0.020 0.022 0.025 0.028 0.032 0.036 0.040 0.045	Volume In % 0.00 0.00 0.00 0.00 0.00 0.00 0.00	Size (µm) 0.142 0.159 0.178 0.200 0.224 0.252 0.283 0.317	Volume In % 0.00 0.00 0.00 0.00 0.00 0.00 0.00	Size (µm) 1.002 1.125 1.262 1.416 1.589 1.783 2.000 2.244	Volume In % 0.00 0.00 0.00 0.00 0.00 0.05 0.15	Size (µm) V 7.096 7.962 8.934 10.024 11.247 12.619 14.159 15.887	0.99 1.14 1.32 1.50 1.70 1.89 2.08	Size(µm) V 50238 56368 63246 70,963 79,621 89,337 100,237 112,468	2.19 2.03 1.86 1.70 1.53 1.38 1.24	Size (µm 355.654 399.052 447.74 502.37 563.67 632.456 709.62 796.21	Volume In % 3 3.33 4 3.72 7 3.69 3 3.50 3 3.17 4 2.72	
	0.050 0.056 0.063 0.071	0.00 0.00 0.00 0.00	0.356 0.399 0.448 0.502	0.00 0.00 0.00 0.00	2.518 2.825 3.170 3.557	0.22 0.27 0.33 0.38	17.825 20.000 22.440 25.179	2.26 2.41 2.53 2.62	126.191 141.589 158.866 178.250	1.13 1.06 1.05 1.11	893.36 1002.374 1124.68 1261.913	7 2.21 1.70 1.22 3 0.82	
	0.080 0.089 0.100	0.00 0.00 0.00	0.564 0.632 0.710	0.00 0.00 0.00	3.991 4.477 5.024	0.43 0.49 0.55	28.251 31.698 35.566	2.66 2.67 2.64	200.000 224.404 251.785	1.25 1.48 1.79	1415.892 1588.656 1782.502	0.50 0.29 0.13	
	0.112 0.126 0.142	0.00 0.00 0.00	0.796 0.893 1.002	0.00 0.00 0.00	5.637 6.325 7.096	0.64 0.73 0.85	39.905 44.774 50.238	2.56 2.46 2.34	282.508 316.979 355.656	2.16 2.57 2.97	2000.000	0.07	

Result Analysis Report

Operator notes:

Malvern Instruments Ltd. Malvem, UK Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789

Mastersizer 2000 Ver. 5.60 Serial Number : MAL1017217 File name: 140227-GrD-IK Record Number: 8 27-02-2014 11:10:58

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				F	Resul	t Analy	ysis R	leport					
Sample I Gr-D-K-A	Name: - Average	e		SOP Nan Flyveask	ne: easke våd	ł		Measu 27. febi	r ed: ruar 2014 1	1:00:08			
Sample S Paris	Source &	type:		Measure f-user	d by:			Analys 27. febr	ed: ruar 2014 1	1:00:10			
Sample k 123-ABC	oulk lot re	f:		Result Se Averaged	ource:								
Particle I aske	Name:			Accesso Hydro 20	ry Name: 00SM (A)			Analys Genera	is model: Il purpose			Sensitivity Enhanced	<i>ı</i> :
Particle 1.500 Dispersa Water	RI: Int Name:			Absorption: 0 Dispersant RI: 1.330				Size ra 0.020 Weight 0.364	Size range: C 0.020 to 2000.000 um 1 Weighted Residual: F 0.364 % C			Obscurati 13.46 % Result Em Off	on: Julation:
Concent 0.0227	ration: %Vol			Span : 2.272				Uniforr 0.704	nity:			Result un Volume	its:
Specific 0.466	Surface A m²/g	Area:		Surface 1 12.868	Weighted um	Mean D[3,	2]:	Vol. We 26.598	eighted Me um	an D[4,3]	:		
d(0.1):	5.572	um			d(0).5): 21.5	97 u	m			d(0.9):	54.641	um
Г	Q	,,			Pa	rticle Size	Distribut	ion					
	c												
	7	/											
	6												
	~ C	,											
	% 5	5											
	e,												
	En 4												
	0/ 3	3											
	- -												
	2	-											
	1												
	ť	0.01	0.1		1		10	1	L00	100	00 30	00	
Ŀ	-Cr-D-K	A - Mers	000 77 fc	bruar 201	4 11.00	Particle Siz	e (μm)						_
	Size/um	Volume le %	Size(um)		Size (um)	Volume In %	Size (um)	/olume In %/	Size (um) 1/2	lume In %	Size (um	Volume In %	
	0.020	0.00	0.142	0.00	1.002	0.00	7.096	2 27	50.238	3.49	355.656		
	0.022	0.00	0.159	0.00	1.125	0.00	7.962	2.55	56.368	2.88	399.052	0.00	
	0.028	0.00	0.200	0.00	1.416	0.00	10.024	2.86	70.963	2.25	502.377	0.00	
	0.032	0.00	0.224	0.00	1.589	0.00	11.247	3.20	79.621	1.06	563.677	0.00	
	0.036	0.00	0.252	0.00	1.783	0.33	12.619 14.159	3.95	89.337	0.71	632.456 709.627	0.00	
	0.045	0.00	0.317	0.00	2.244	0.48	15.887	4.33	112.468	0.36	796214	0.00	
	0.050	0.00	0.356	0.00	2.518	0.81	17.825	5.03	126.191	0.02	893.367	0.00	
	0.056	0.00	0.399	0.00	3.170	0.96	20.000	5.29	158.866	0.00	1124.685	0.00	
	0.071	0.00	0.502	0.00	3.557	1.10	25.179	5.48	178.250	0.00	1261.915	0.00	
	0.080	0.00	0.564	0.00	3.991 4.477	1.36	28.251	5.51	200.000	0.00	1415.892	0.00	
	0.100	0.00	0.710	0.00	5.024	1.49	35.566	5.33	251.785	0.00	1782.502	0.00	
	0.112	0.00	0.796	0.00	5.637	1.83	39.905	4.61	282.508	0.00	2000.000	0.00	
	0.126	0.00	0.893	0.00	6.325	2.03	44.774 50.238	4.09	316.979 355.656	0.00			

Operator notes:

Malvem Instruments Ltd. Malvem, UK Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789 Mastersizer 2000 Ver. 5.60 Serial Number : MAL1017217 File name: 140227-GrD-IK Record Number: 12 27-02-2014 11:11:26





Sample N Gr-D-K-B	Name: - Average	i		SOP Nan Flyveask	ne: easke våd	Ĩ		Measu 27. febi	r ed: ruar 2014	11:06:21			
Sample S Paris	Source & 1	type:		Measure f-user	d by:			Analys 27. febr	ed: ruar 2014	11:06:22			
Sample b 123-ABC	oulk lot ret	f:		Result Se Averaged	ource:								
Particle Name: aske			Accessory Name:				Analys Genera	Analysis model: General purpose			Sensitivity:		
Particle I 1.500 Dispersa Water	Absorption: Size range: Obscu 0 0.020 to 2000.000 um 14.33 Sant Name: Dispersant RI: Weighted Residual: Result 1.330 0.370 % Off				Obscurat 14.33 9 Result En Off	ion: % nulation:							
Concentr 0.0256	r ation: %Vol			Span : 2.741				Uniforr 0.851	nity:			Result un Volume	its:
Specific Surface Area: 0.442 m²/g				Surface 1 13.583	Weighted um	Mean D[3	2]:	Vol. We 32.830	eighted N um	/lean D[4,3]:		
d(0.1):	5.604	um			d(0	0.5): 24.3	339 u	im			d(0.9):	72.314	um
Г					Ра	rticle Size	Distribut	tion					
	6												
	5						/						
	(%							· \					
	<u>ຍ</u> 4												
	۲ n												
	lov vol	0											
	2												
	1												
	Q												
	0	.01	0.:		1		10	1	100	10	00 30	00	
						Particle Si	ze (µm)						_
E	-Gr-D-K-	B - Avera	ige, 27. fe	ebruar 201	4 11:06:	21							
	Size (µm) 0.020	Volume In %	Size (µm) 0.142	Volume In %	Size (µm) 1.002	Volume In %	Size (µm) 7,096	Volume In %	Size (µm) 50.238	Volume In %	Size (µm) 355,656	Volume In %	
	0.022	0.00	0.159	0.00	1.125	0.00	7.962	2.19	56.368	3.94	399.052	0.00	
	0.025	0.00	0.178	0.00	1.262	0.00	8.934	2.64	63.246 70.963	3.17	447.744	0.00	
	0.032	0.00	0.224	0.00	1.589	0.00	11.247	2.89	79.621	2.73	563.677	0.00	
	0.036	0.00	0.252	0.00	1.783	0.30	12.619	3.42	89.337	1.82	632.456	0.00	
	0.040	0.00	0.283	0.00	2.000	0.46	15.887	3.68	112.468	1.40	796214	0.00	
	0.050	0.00	0.356	0.00	2.518	0.63	17.825	3.94 4.18	126.191	1.01	893.367	0.00	
	0.056	0.00	0.399	0.00	2.825	0.95	20.000	4.39	141.589	0.41	1002.374	0.00	
	0.063	0.00	0.448	0.00	3.557	1.09	25.179	4.56	178.250	0.17	1261.915	0.00	
	0.080	0.00	0.564	0.00	3.991	1.23	28.251	4.68	200.000	0.00	1415.892	0.00	
	0.089	0.00	0.632	0.00	4.477	1.51	31.698	4.72	224.404	0.00	1588.656	0.00	
	0.112	0.00	0.796	0.00	5.637	1.65	39.905	4.64	282.508	0.00	2000.000	0.00	
	0.126	0.00	0.893	0.00	6.325	2.00	44.774	4.47	316.979	0.00			

Result Analysis Report

Operator notes:

Malvern Instruments Ltd. Malvem, UK Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789

Mastersizer 2000 Ver. 5.60 Serial Number : MAL1017217 File name: 140227-GrD-IK Record Number: 16 27-02-2014 11:11:43

G.4 Preliminary part: Compressive strength

5 9	% cement		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	585,46	160,20	40,06	40,83	33,00	33,00	33,00
В	585,65	160,20	40,03	40,87	32,00	31,00	31,50
С	589,88	160,10	40,04	40,97	34,00	30,00	32,00
						Gs. Total	32,17

1	0 % sand		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	563,24	160,90	39,79	39,33	31,00	31,00	31,00
В	566,00	160,70	39,84	39,60	32,00	31,00	31,50
С	573,87	160,68	39,79	40,01	32,00	32,00	32,00
						Gs. Total	31,50

	REF		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	575,70	160,75	40,33	41,25	34,00	31,00	32,50
В	572,31	160,75	40,17	41,00	35,00	30,00	32,50
С	564,20	160,00	40,00	39,00	30,00	34,00	32,00
						Gs. Total	32,33

	REF		2 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	590,70	160,60	40,10	41,50	47,00	53,00	50,00
В	589,95	160,40	39,90	40,70	44,00	46,00	45,00
С	588,25	160,90	40,10	41,10	41,00	49,00	45,00
						Gs. Total	46,67

5	% cement		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	590,36	160,70	39,92	40,82	63,00	61,00	62,00
В	588,23	160,50	40,09	40,66	57,00	53,00	55,00
С	584,64	160,10	39,96	40,56	59,00	59,00	59,00
						Gs. Total	5 <mark>8,67</mark>

1	0 % sand		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	562,71	160,30	39,99	39,37	60,00	60,00	60,00
В	588,65	160,30	40,10	41,25	62,00	65,00	63,50
С	587,29	160,30	40,14	41,19	61,00	66,00	63,50
						Gs. Total	62,33

	REF		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	586,31	160,80	40,10	41,10	65,00	65,00	65,00
В	592,57	160,10	40,00	40,50	64,00	64,00	64,00
С	581,18	160,30	40,00	40,60	67,00	66,00	66,50
						Gs. Total	65,17

	REF		4 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	591,19	160,70	40,16	40,77	67,00	67,00	67,00
В	589,62	160,20	40,04	40,41	66,00	63,00	64,50
С	591,57	160,10	39,99	40,73	68,00	66,00	67,00
						Gs. Total	66,17

5	% cement		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	580,62	159,60	39,93	40,71	63,00	64,00	63,50
В	580,60	159,90	39,91	40,78	60,00	60,00	60,00
С	584,69	160,00	39,91	40,94	58,00	65,00	61,50
						Gs. Total	61,67

1	0 % sand		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	577,51	160,30	39,94	40,30	71,00	70,00	70,50
В	570,71	160,50	40,02	40,25	70,00	65,00	67,50
С	571,72	160,50	39,88	40,05	69,00	69,00	69,00
		-				Gs. Total	69,00

	REF		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	577,00	160,90	40,10	40,20	73,00	76,00	74,50
В	574,00	160,80	40,00	39,70	72,00	72,00	72,00
С	573,00	160,60	40,00	39,80	75,00	73,00	74,00
						Gs. Total	73,50

5	% cement		7 døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	592,92	160,90	40,04	40,56	72,00	73,00	72,50
В	593,96	160,10	39,97	40,84	70,00	70,00	70,00
С	593,96	160,33	40,03	40,90	69,00	71,00	70,00
						Gs. Total	70,83

1	.0 % sand		7 døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	580,17	160,83	39,95	40,18	83,00	83,00	83,00
В	576,66	160,90	39,85	40,22	71,00	72,00	72,00
С	586,31	160,93	40,10	40,33	86,00	83,00	84,50
				-		Gs. Total	79.83

Preliminary part: Setting G.5

	REF						
	Test number	DRAEN6					
	Kind of test	90 DROP					
	Cycle tyoe	STANDARD					
	Operator code	VS14					
	Customer code	MSML14					
	Date of test	02.04.2014					
	Specimen time	KI. 14:42:06					
	Start delay	7					
	1 st nen time	-					
	Specimen type	DRAENBOG					
	Water cont	12 50					
	Temperatur	20.00					
	Humidity	60.00					
	Fall type	EDEE					
	Time tune						
	Time type	FIXED					
	Final setting	10.00					
	lime	10,00					
	DEN [mm]						
1		ן נא <u>ן</u> ד					
2	0,0	17					
2	0,0	27					
ر ۸	0,0	27					
4	0,0	37					
2	0,0	47					
0	0,0	57					
/	0,0	67					
ŏ	0,0	//					
9	0,0	8/					
10	0,0	97					
11	0.0	1/1//					
		107					
12	0,0	107					
12	0,0 0,0	107 117 127					
12 13 14	0,0 0,0 8,5	107 117 127 137					
12 13 14 15	0,0 0,0 8,5 0,0	107 117 127 137 147					
12 13 14 15 16	0,0 0,0 8,5 0,0 0,0	107 117 127 137 147 157					
12 13 14 15 16 17	0,0 0,0 8,5 0,0 0,0 9,3	107 117 127 137 147 157 167					
12 13 14 15 16 17 18	0,0 0,0 8,5 0,0 0,0 9,3 18,9	107 117 127 137 147 157 167 177					
12 13 14 15 16 17 18 19	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9	107 117 127 137 147 157 167 177 187					
12 13 14 15 16 17 18 19 20	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9 23,7	107 117 127 137 147 157 167 177 187 197					
12 13 14 15 16 17 18 19 20 21	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9 23,7 28,6	107 117 127 137 147 157 167 177 187 197 207					
12 13 14 15 16 17 18 19 20 21 22	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9 23,7 28,6 31,2	107 117 127 137 147 157 167 177 187 197 207 217					
12 13 14 15 16 17 18 19 20 21 22 23	0,0 0,0 8,5 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5	107 117 127 137 147 157 167 177 187 197 207 217 227					
12 13 14 15 16 17 18 19 20 21 22 23 24	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5 34,9	107 117 127 137 147 157 167 177 187 197 207 217 227 237					
12 13 14 15 16 17 18 19 20 21 22 23 24 25	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5 34,9 34,5	107 117 127 137 147 157 167 177 187 197 207 217 227 237 247					
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26	0,0 0,0 8,5 0,0 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5 34,9 34,5 35,2	107 117 127 137 147 157 167 177 187 197 207 217 227 237 247 257					
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27	0,0 0,0 8,5 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5 34,9 34,5 35,2 37,1	107 117 127 137 147 157 167 177 187 197 207 217 227 237 247 257 267					
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	0,0 0,0 8,5 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5 34,9 34,5 34,5 35,2 37,1 37,6	107 117 127 137 147 157 167 177 187 197 207 217 227 237 247 257 267 277					
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29	0,0 0,0 8,5 0,0 9,3 18,9 21,9 23,7 28,6 31,2 30,5 34,9 34,5 34,5 35,2 37,1 37,6 37,8	107 117 127 137 147 157 167 177 187 197 207 217 227 237 247 257 267 277 287					

ID	PEN [mm]	[s]
31	38,7	307
32	38,1	317
33	37,9	327
34	38,5	337
35	39,3	347
36	38,6	357
37	38,2	367
38	38,1	377
39	38,0	387
40	38,3	397
41	38,2	407
42	38,4	417
43	38,7	427
44	38,2	437
45	38,5	447
46	39,0	457
47	39,0	467
48	38,7	477
49	39,1	487
50	39,3	497
51	39,4	507
52	39,6	517
53	39,6	527
54	39,9	537
55	39,8	547
56	39,6	557
57	39,7	567
58	39,9	577
59	39,5	587
60	39.4	597

ID	PEN [mm]	[s]
61	39,0	607
62	39,4	617
63	39,2	627
64	39,0	637
65	38,8	647
66	39,4	657
67	39,2	667
68	39,3	677
69	39,2	687
70	39,6	697
71	39,8	707
72	40,1	717
73	40,1	727
74	39,9	737
75	39,9	747
76	39,6	757
77	39,5	767
78	39,5	777
79	39,7	787
80	39,3	797
81	39,2	807
82	39,0	817
83	39,3	827
84	39,6	837
85	39,9	847
86	40,2	857
87	39,80	867
88	39,30	877
89	39,00	887
90	39,50	897

5 % cement				
Test number	GRD5PCT			
Kind of test	90 DROP			
Cycle tyoe	STANDARD			
Operator code	VS14			
Customer code	SLR14			
Date of test	07.04.2014			
Specimen time	Kl. 08:48:29			
Start delay	7			
1 st pen time	U.			
Specimen type	DRAENB06			
Water cont.	12,50			
Temperatur	20,00			
Humidity	60,00			
Fall type	FREE			
Time type	FIXED			
Final setting	NO			
Time	10,00			

ID	PEN [mm]	[s]
1	0,0	7
2	0,0	17
3	0,0	27
4	0,0	37
5	0,0	47
6	0,0	57
7	0,0	67
8	0,0	77
9	0,0	87
10	0,0	97
11	0,0	107
12	0,0	117
13	0,0	127
14	0,0	137
15	0,0	147
16	13,0	157
17	18,7	167
18	0,0	177
19	17,8	187
20	14,9	197
21	14,8	207
22	29,4	217
23	38,1	227
24	33,0	237
25	33,1	247
26	40,9	257
27	43,2	267
28	43,9	277
29	44,9	287
30	44,3	297

ID	PEN [mm]	[s]
31	44,6	307
32	44,3	317
33	44,4	327
34	44,9	337
35	44,7	347
36	43,7	357
37	44,6	367
38	43,7	377
39	42,8	387
40	42,4	397
41	43,2	407
42	43,7	417
43	44,1	427
44	43,5	437
45	44,0	447
46	44,9	457
47	44,5	467
48	44,5	477
49	44,7	487
50	44,8	497
51	45,0	507
52	45,3	517
53	45,1	527
54	45,8	537
55	45,2	547
56	45,6	557
57	44,9	567
58	44,8	577
59	44,6	587
60	45,4	597

ID	PEN [mm]	[s]
61	45,0	607
62	44,0	617
63	43,9	627
64	44,4	637
65	44,3	647
66	44,1	657
67	44,2	667
68	44,6	677
69	44,4	687
70	45,5	697
71	44,4	707
72	45,6	717
73	45,0	727
74	44,9	737
75	46,4	747
76	44,7	757
77	44,7	767
78	44,7	777
79	45,0	787
80	44,4	797
81	45,2	807
82	44,4	817
83	44,9	827
84	44,1	837
85	44,9	847
86	45,0	857
87	45,6	867
88	44,1	877
89	45,5	887
90	44,2	897

10 % sand				
Test number	GRD10PCT			
Kind of test	90 DROP			
Cycle tyoe	STANDARD			
Operator code	VS14			
Customer code	SLR14			
Date of test	09.04.2014			
Specimen time	Kl. 08:53:24			
Start delay	7			
1 st pen time	U.			
Specimen type	DRAENB06			
Water cont.	12,50			
Temperatur	20,00			
Humidity	60,00			
Fall type	FREE			
Time type	FIXED			
Final setting	NO			
Time	10,00			

ID	PEN [mm]	[S]
1	0,0	7
2	0,0	17
3	0,0	27
4	0,0	37
5	0,0	47
6	0,0	57
7	0,0	67
8	0,0	77
9	0,0	87
10	0,0	97
11	0,0	107
12	0,0	117
13	0,0	127
14	0,0	137
15	0,0	147
16	0,0	157
17	0,0	167
18	0,0	177
19	0,0	187
20	0,0	197
21	0,0	207
22	0,0	217
23	0,0	227
24	0,0	237
25	3,7	247
26	7,8	257
27	3,2	267
28	11,7	277
29	17,4	287
30	30,1	297

ID	PEN [mm]	[s]
31	33,4	307
32	37,5	317
33	38,4	327
34	38,0	337
35	38,0	347
36	40,8	357
37	41,8	367
38	41,1	377
39	39,3	387
40	42,4	397
41	42,2	407
42	42,2	417
43	40,7	427
44	42,7	437
45	43,4	447
46	44,3	457
47	42,3	467
48	42,2	477
49	45,7	487
50	42,4	497
51	43,5	507
52	43,4	517
53	43,4	527
54	43,7	537
55	43,5	547
56	44,1	557
57	43,4	567
58	42,6	577
59	41,6	587
60	43,5	597

ID	PEN [mm]	[s]	
61	43,5	607	
62	43,0	617	
63	44,0	627	
64	43,5	637	
65	44,1	647	
66	44,4	657	
67	44,3	667	
68	46,8	677	
69	44,9	687	
70	43,2	697	
71	42,8	707	
72	45,7	717	
73	45,6	727	
74	44,8	737	
75	42,8	747	
76	42,6	757	
77	44,1	767	
78	44,3	777	
79	44,5	787	
80	43,9	797	
81	43,1	807	
82	43,4	817	
83	44,5	827	
84	43,3	837	
85	44,0	847	
86	44,1	857	
87	43,0	867	
88	43,5	877	
89	43,7	887	
90	44.6	897	

G.6 Preliminary part: Porosity and density

T _{rum}	21	°C
T _{vand}	21	°C
ρ_{vand}	998	kg/m ³

5c 7d	А	В	С	Gs.
m ₅₀	0,54	0,54	0,55	0,54
m _{ssd}	0,59	0,59	0,60	0,59
m _{sw}	0,34	0,34	0,34	0,34
V	0,00026	0,00026	0,00026	0,00026
V _{på}	0,00005	0,00005	0,00005	0,00005
p _å	0,19	0,20	0,19	0,1939
ρ _d	2106,16	2095,08	2106,21	2102,48
ρ _f	2609,07	2605,49	2610,48	2608,35
ρ _{ssd}	2298,53	2290,59	2299,00	2296,04
u _{ssd}	0,09	0,09	0,09	0,09

10s 7d	А	В	С	Gs.
m ₅₀	0,54	0,53	0,53	0,53
m _{ssd}	0,59	<mark>0,58</mark>	0,58	0,59
m _{sw}	0,33	0,33	0,33	0,33
V	0,00026	0,00026	0,00026	0,00026
V _{på}	0,00005	0,00005	0,00005	0,00005
p _å	0,21	0,21	0,21	0,2093
ρ _d	2070,71	2061,90	2064,19	2065,60
ρ _f	2613,65	2611,96	2611,11	2612,24
ρ _{ssd}	2278,03	2272,07	2273,23	2274,44
u _{ssd}	0,10	0,10	0,10	0,10

5c 14d	A	В	С	Gs.
m ₅₀	0,55	0,55	0,55	0,55
m _{ssd}	0,60	0,60	0,59	0,60
m _{sw}	0,34	0,34	0,34	0,34
V	0,00026	0,00026	0,00026	0,00026
V_{pa}	0,00005	0,00005	0,00005	0,00005
p _å	0,19	0,19	0,19	0,1873
ρ _d	2109,48	2108,02	2113,83	2110,44
ρ _f	2596,48	2595 <mark>,</mark> 03	2598,69	2596,73
ρ_{ssd}	2296,67	2295,32	2300,04	2297,34
u _{ssd}	0,09	0,09	0,09	0,09

10s 14d	А	В	С	Gs.
m ₅₀	0,53	0,54	0,54	0,54
m _{ssd}	0,59	0,59	0,60	0,59
m _{sw}	0,33	0,33	0,33	0,33
V	0,00026	0,00026	0,00027	0,00026
V _{på}	0,00005	0,00005	0,00006	0,00006
p _å	0,21	0,21	0,23	0,2137
ρ _d	2070,51	2065,31	2008,28	2048,03
ρ _f	2606,28	2603,40	2604,44	2604,71
ρ _{ssd}	2275,67	2271,58	2236,73	2261,32
u _{ssd}	0,10	0,10	0,11	0,10

5c 28d	А	В	С	Gs.
m ₅₀	0,54	0,54	0,54	0,54
m _{ssd}	0,59	0,59	0,59	0,59
m _{sw}	0,33	0,33	0,34	0,33
V	0,00026	0,00026	0,00026	0,00026
V _{på}	0,00005	0,00005	0,00005	0,00005
p _å	0,19	0,19	0,19	0,1882
ρ _d	2100,99	2097,18	2123,88	2107,35
ρ _f	2586,61	2586,36	2614,67	2595,88
ρ _{ssd}	2288,36	2285,94	2311,21	2295,17
u _{ssd}	0,09	0,09	0,09	0,09

10s 28d	А	В	С	Gs.
m ₅₀	0,54	0,54	0,54	0,54
m _{ssd}	0,59	0,59	0,59	0,59
m _{sw}	0,33	0,33	0,33	0,33
V	0,00026	0,00026	0,00026	0,00026
V _{på}	0,00005	0,00005	0,00005	0,00005
p _å	0,20	0,20	0,20	0,1984
ρ _d	2074,71	2071,51	2075,78	2074,00
ρ _f	2586,45	2585,35	2589,84	2587,22
ρ _{ssd}	2272,17	2269,86	2273,88	2271,97
u _{ssd}	0,10	0,10	0,10	0,10

REF 28d	Α	В	С	Gs.
m ₅₀	0,55	0,55	0,56	0,55
m _{ssd}	0,60	0,60	0,61	0,60
m _{sw}	0,34	0,34	0,34	0,34
V	0,00026	0,00026	0,00026	0,00026
V_{pa}	0,00005	0,00005	0,00005	0,00005
p _å	0,19	0,19	0,19	0,1878
ρ _d	2107,37	2104,86	2115,41	2109,21
ρ _f	2596,07	2597,15	2597,65	2596,96
ρ_{ssd}	2295,24	2294,03	2300,68	2296,65
u _{ssd}	0,09	0,09	0,09	0,09

Symbol	Enhed	Forklaring
m ₅₀	kg	Masse efter tørring
m _{ssd}	kg	Masse i luft af vakuumvandmættet prøvelegeme i overfladetør tilstand
m _{sw}	kg	Masse af vakuumvandmættet prøvelegeme i overfladetør tilstand
v	m ³	Prøvelegemets volumen
V_{pa}	m ³	Volumen af åbne porer
p _å	m³/m³	Prøvelegemets åbne porøsitet
ρ _d	kg/m ³	Tørstofdensitet
ρ _f	kg/m ³	Faststofdensitet
ρ_{ssd}	kg/m ³	Densitet af prøvelegeme i vakuumvandmættet overfladetør tilstand
u _{ssd}	kg/kg	Vandtørstofforhold i vakuumvandmættet overfladetør tilstand

5c 7d	А			В		С	Gs.
t [min]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m²]
0	0,54414	0,0000000	0,54342	0,0000000	0,54637	0,0000000	0,0000000
1	0,54605	0,2970271	0,54532	0,2965048	0,54853	0,3372049	0,3102456
2	0,54697	0,4400977	0,54613	0,4229095	0,54941	0,4745847	0,4458640
4	0,54799	0,5987195	0,54711	0,5758436	0,55049	0,6431872	0,6059168
8	0,5493	0,8024397	0,54832	0,7646704	0,5518	0,8476958	0,8049353
16	0,55122	1,1010219	0,55012	1,0455697	0,55392	1,1786562	1,1084159
32	0,55396	1,5271235	0,55265	1,4403893	0,5567	1,6126514	1,5267214
60	0,55717	2,0263157	0,55575	1,9241603	0,56002	2,1309479	2,0271413
120	0.56169	2.7292279	0,56029	2,6326508	0,56479	2,8756088	2,7458292

G.7	Preliminary part:	Capillary	suction
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h [mm]	40,76		
A [mm ²]	6430,39		
	3		
h [mana]	40.00		
n [mm]	40,89		
A [mm ²]	6407,99		
С			

Α

h [mm]	40,94
A [mm ²]	6405,6

A h [mm]

A [mm²] 6399,94

B h [mm]

A [mm²]

40,97

40,71

6432,03

5c 14d		Α		В		С	Gs.
t [min]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m²]
0	0,5469	0,0000000	0,54948	0,0000000	0,54661	0,0000000	0,0000000
1	0,54864	0,2718775	0,55124	0,2736306	0,54849	0,2934570	0,2796550
2	0,54962	0,4250040	0,55209	0,4057817	0,54937	0,4308199	0,4205352
4	0,55049	0,5609428	0,553	0,5472611	0,55034	0,5822312	0,5634784
8	0,55168	0,7468820	0,55407	0,7136161	0,55152	0,7664223	0,7423068
16	0,55317	0,9796967	0,55553	0,9406051	0,55321	1,0302214	0,9835077
32	0,55538	1,3250124	0,55765	1,2702055	0,55569	1,4173349	1,3375176
60	0,55817	1,7609540	0,56037	1,6930891	0,55879	1,9012267	1,7850900
120	0,56226	2,4000225	0,56436	2,3134220	0,5633	2,6052114	2,4395520

(2
h [mm]	40,78
A [mm ²]	6406,39

5c 28d		Α		В		С	Gs.
t [min]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m²]
0	0,54171	0,0000000	0,53954	0,0000000	0,54261	0,0000000	0,0000000
1	0,54351	0,2811468	0,54144	0,2949546	0,54448	0,2912042	0,2891019
2	0,54432	0,4076628	0,5422	0,4129364	0,54526	0,4126691	0,4110894
4	0,54523	0,5497981	0,54316	0,5619661	0,54612	0,5465919	0,5527854
8	0,54638	0,7294197	0,54435	0,7467008	0,54728	0,7272320	0,7344508
16	0,548	0,9824518	0,54596	0,9966360	0,54884	0,9701617	0,9830831
32	0,55026	1,3354471	0,54819	1,3428195	0,55096	1,3002970	1,3261879
60	0,55331	1,8118347	0,551	1,7790418	0,55369	1,7254240	1,7721002
120	0,55736	2,4444149	0,55516	2,4248370	0,55773	2,3545497	2,4079339

А				
h [mm]	40,57			
A [mm ²]	6402,35			

В				
h [mm]	40,49			
A [mm ²]	6441,67			

С				
h [mm]	40,55			
A [mm ²]	6421,61			

10s 28d

t [min]

Α

120 0,55023 2,0333272 0,55546 2,1370900

10s 7d	A			В		С	Gs.
t [min]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m²]
0	0,54046	0,0000000	0,53006	0,0000000	0,52701	0,0000000	0,0000000
1	0,54211	0,2551604	0,53182	0,2734970	0,52871	0,2648982	0,2645186
2	0,54286	0,3711424	0,53265	0,4024758	0,52949	0,3864397	0,3866860
4	0,5438	0,5165066	0,53362	0,5532099	0,53036	0,5220052	0,5305739
8	0,54503	0,7067171	0,53489	0,7505629	0,53168	0,7276909	0,7283236
16	0,54663	0,9541454	0,53648	0,9976426	0,53322	0,9676575	0,9731485
32	0,54882	1,2928128	0,53862	1,3301902	0,53529	1,2902100	1,3044043
60	0,55138	1,6886981	0,54118	1,7280041	0,53786	1,6906737	1,7024586
120	0,55525	2,2871653	0,54488	2,3029695	0,5417	2,2890320	2,2930556

1	٩		
h [mm]	40,71		
A [mm ²]	6466,52		
В			

h [mm]	40,33
A [mm ²]	6435,17

(2
h [mm]	40,04
A [mm ²]	6417,56

Α h [mm]

A [mm²] 6443,20

В h [mm]

A [mm²] 6448,81

A [mm²] 6433,11

h [mm]

40,26

41,05

40,95

10s 14d	A			В		С	Gs.
t [min]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m ²]
0	0,53468	0,0000000	0,53967	0,0000000	0,53793	0,0000000	0,0000000
1	0,53625	0,2436677	0,54137	0,2636145	0,53954	0,2502678	0,2525167
2	0,53703	0,3647256	0,54225	0,4000738	0,54034	0,3746244	0,3798079
4	0,53806	0,5245841	0,54335	0,5706479	0,54133	0,5285158	0,5412492
8	0,53933	0,7216911	0,54473	0,7846409	0,54264	0,7321498	0,7461606
16	0,54089	0,9638068	0,54645	1,0513568	0,54432	0,9932987	1,0028208
32	0,54317	1,3176682	0,54881	1,4173158	0,54667	1,3585964	1,3645268
60	0,54592	1,7444748	0,5517	1,8654604	0,54958	1,8109437	1,8069596
120	0,54988	2,3590762	0,5559	2,5167434	0,55377	2,4622616	2,4460271

В

Α	Gs.	С	
h [mm]	Q [kg/m²]	Q [kg/m²]	t [kg]
A [mm ²]	0,000000	0,0000000	54039
	0,2408392	0,2454045	54196
В	0,3795035	0,3782669	54281
h [mm]	0,4988825	0,5001876	54359
A [mm ²]	0 6443260	0 6408653	54449

in]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m²]	ŀ
0	0,53722	0,0000000	0,54181	0,0000000	0,54039	0,0000000	0,0000000	A
1	0,5387	0,2313085	0,54338	0,2458045	0,54196	0,2454045	0,2408392	
2	0,53961	0,3735321	0,54428	0,3867115	0,54281	0,3782669	0,3795035	
4	0,54032	0,4844976	0,54508	0,5119622	0,54359	0,5001876	0,4988825	ŀ
8	0,54124	0,6282840	0,54605	0,6638287	0,54449	0,6408653	0,6443260	A
16	0,54253	0,8298976	0,54739	0,8736236	0,54582	0,8487558	0,8507590	
32	0,54437	1,1174704	0,54932	1,1757909	0,54764	1,1332375	1,1421662	
60	0,54672	1,4847508	0,55178	1,5609368	0,54993	1,4911842	1,5122906	h

0,5534 2,0335751 2,0679974

	-	-
۲	n [mm]	40,78
A	\[mm ²]	6398,38
_		
Г	E	3

h [mm]	41,25
A [mm ²]	6387,19

(2
h [mm]	41,29
A [mm ²]	6397,60

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REF 28d		Α		В		С	Gs.	A	ι
t [min]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	m _t [kg]	Q [kg/m²]	Q [kg/m²]	h [mm]	160,00
0	0,54539	0,0000000	0,54987	0,0000000	0,5569	0,0000000	0,0000000	A [mm ²]	1644,18
1	0,546	0,3710056	0,55046	0,3588590	0,55748	0,3502733	0,3600459		
2	0,54621	0,4987288	0,55066	0,4805061	0,55769	1,7672037	0,9154795	E	3
4	0,54643	0,6325342	0,55086	0,6021532	0,55789	1,7984264	1,0110379	h [mm]	160,00
8	0,54672	0,8089139	0,55113	0,7663767	0,55818	1,8436993	1,1396633	A [mm²]	1644,10
16	0,54707	1,0217859	0,55148	0,9792592	0,55855	1,9014612	1,3008354		
32	0,54757	1,3258889	0,55198	1,2833769	0,55906	1,9810791	1,5301150	(2
60	0,54822	1,7212227	0,55264	1,6848124	0,55971	2,0825528	1,8295293	h [mm]	162,00
120	0,54925	2,3476748	0,55366	2,3052126	0,56071	2,2386662	2,2971845	A [mm ²]	1655,85

G.8 Preliminary part: Flow of hydraulic cement mortar

Sætmål							
Prøve	D1 [mm]	D2 [mm]	Gs. [mm]				
REF	158	156	157,0				
5 % cement	148	144	146,0				
10 % sand	144,5	142	143,3				

G.9 Further part: Mass of NH₄H₂PO₄

M(NH4H2PO4) [g/mol]	115,024	
Koncentration [mol/L]	Volumen [L]	m(NH4H2PO4)
0,08	0,225	2,11
0,10	0,225	2,59
0,25	0,240	6,90
0,50	0,250	14,38
1,00	0,275	31,63

G.10 Further part: Compressive strength

R	EF 0,1 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	585,18	160,00	40,00	40,95	34,00	35,00	34,50
В	581,61	160,00	40,00	81,40	34,00	34,00	34,00
С	586,01	160,00	40,00	40,93	35,00	34,00	34,50
						Gs. Total	34,33

R	EF 0,25 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	580,31	160,30	40,10	40,65	9,00	9,00	9,00
В	577,54	160,20	40,10	40,60	9,00	9,00	9,00
С	584,96	160,20	40,10	41,08	10,00	10,00	10,00
						Gs. Total	9,33

R	EF 0,5 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α							0,00
В			Kan ikke	Kan ikke afformes			0,00
С							0,00
						Gs. Total	0,00

	REF 1 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	558,08	160,00	40,00	40,48	8,00	8,00	8,00
В	559,52	160,00	40,00	40,45	8,00	6,00	7,00
С	565,53	160,00	40,00	40,73	8,00	6,00	7,00
						Gs. Total	7.33

	5c 0,1 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	586,42	160,05	40,05	41,35	28,00	28,00	28,00
В	580,50	160,10	40,20	41,05	28,00	26,00	27,00
С	584,73	160,00	40,05	41,20	29,00	21,00	25,00
						Gs. Total	26,67

5	ic 0,25 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
А	582,06	160	40,15	41,18	11,00	11,00	11,00
В	582,02	160	40,15	41,15	11,00	11,00	11,00
С	582,21	160	40,10	41,10	11,00	12,00	11,50
						Gs. Total	11,17

	5c 0,5 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
А							0,00
В			Kan ikke	Kan ikke afformes			0,00
С							0,00
						Gs. Total	0,00

	5c 1 M		1 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	560,79	160,00	40,00	40,75	7,00	6,00	6,50
В	555,84	160,00	40,05	40,18	5,00	7,00	6,00
С	563,88	160,00	40,03	40,75	7,00	7,00	7,00
						Gs. Total	6.50

R	EF 0,1 M		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	582,69	160,10	40,00	40,25	65,00	66,00	65,50
В	583,88	160,15	40,00	40,75	60,00	65,00	62,50
С	586,03	160,15	40,00	40,60	66,00	63,00	64,50
						Gs. Total	64,17

R	EF 0,25 M		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	575,63	160,00	40,13	40,40	55,00	51,00	53,00
В	574,67	160,05	40,15	40,48	55,00	54,00	54,50
С	580,1	160,05	40,10	40,90	52,00	48,00	50,00
						Gs. Total	52,50

R	REF 0,5 M		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	575,77	160,00	40,13	40,78	26,00	30,00	28,00
В	443,02	160,00	40,15	40,70	15,00	28,00	21,50
С	563,86	160,10	40,18	40,73	24,00	25,00	24,50
						Gs. Total	24,67

REF 1 M			3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	570,57	160,00	40,00	40,98	28,00	26,00	27,00
В	568,25	160,00	40,00	40,85	25,00	27,00	26,00
С	571,32	160,00	40,00	40,93	28,00	29,00	28,50
						Gs. Total	27,17

	5c 0,1 M		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	588,91	160,10	40,00	40,95	61,00	63,00	62,00
В	582,25	160,10	40,00	40,60	56,00	61,00	58,50
С	581,86	160,15	40,00	40,45	62,00	61,00	61,50
						Gs. Total	60,67

5	ic 0,25 M		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	585,68	160,00	40,10	41,03	54,00	51,00	52,50
В	580,4	160,00	40,15	40,65	51,00	50,00	50,50
С	584,72	160,00	40,10	40,93	54,00	51,00	52,50
						Gs. Total	51,83

5c 0,5 M			3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	553,25	160,00	40,13	39,25	21,00	30,00	25,50
В	569,45	160,00	40,18	40,58	27,00	29,00	28,00
С	576,62	160,00	40,13	40,78	31,00	27,00	29,00
						Gs. Total	27,50

	5c 1 M		3 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	567,90	160,00	40,00	40,50	25,00	26,00	25,50
В	560,64	160,00	40,00	40,18	24,00	22,00	23,00
С	569,58	160,00	40,00	40,73	26,00	25,00	25,50
		-	-	-		Gs. Total	24,67

REF 0,1 M			5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	589,63	160,00	40,10	40,95	72,00	76,00	74,00
В	586,92	160,10	40,20	40,78	77,00	75,00	76,00
С	587,34	160,00	40,25	40,75	77,00	77,00	77,00
						Gs. Total	75,67

R	EF 0,25 M]	5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	590,75	161,00	40,00	40,95	71,00	71,00	71,00
В	589,98	160,90	40,10	40,90	68,00	64,00	66,00
С	590,23	161,00	40,10	40,75	69,00	70,00	69,50
						Gs. Total	68,83

F	REF 0,5 M		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	580,82	159,90	39,90	40,88	55,00	53,00	54,00
В	581,27	159,90	39,98	40,95	50,00	51,00	50,50
С	579,07	159,95	40,00	40,68	51,00	52,00	51,50
						Gs. Total	52,00

	REF 1 M		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	571,98	160,10	40,10	40,80	38,00	39,00	38,50
В	569,99	160,20	40,10	40,88	37,00	39,00	38,00
С	569,28	160,10	40,10	40,85	40,00	38,00	39,00
						Gs. Total	38.50

	5c 0,1 M		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	569,28	160,00	40,10	39,85	66,00	67,00	66,50
В	572,63	160,00	40,10	40,05	66,00	63,00	64,50
С	579,50	160,00	40,10	40,50	64,00	68,00	66,00
						Gs. Total	65,67

5	ic 0,25 M		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	579,40	160,10	40,10	40,70	61,00	61,00	61,00
В	580,01	160,10	40,05	40,65	62,00	66,00	64,00
С	577,88	160,10	40,05	40,30	63,00	62,00	62,50
						Gs. Total	62,50

	5c 0,5 M		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	576,34	160,65	39,98	40,48	52,00	51,00	51,50
В	567,59	160,65	40,08	39,85	52,00	54,00	53,00
С	581,57	160,50	40,20	40,63	53,00	52,00	52,50
						Gs. Total	52,33

	5c 1 M		5 Døgn				
Prøve	Masse [g]	Højde [mm]	Bredde [mm]	Dybde [mm]	Styrke 1 [kN]	Styrke 2 [kN]	Gs. [kN]
Α	565,44	160,00	40,10	40,95	35,00	34,00	34,50
В	567,13	160,10	40,10	40,80	31,00	32,00	31,50
С	567,90	160,00	40,10	40,90	33,00	33,00	33,00
						Gs. Total	33,00

G.11 Further part: Setting

0.10 M REF			
Test number	DRAEN6		
Kind of test	90 DROP		
Cycle tyoe	STANDARD		
Operator code	VS14		
Customer code	MSML14		
Date of test	05.05.2014		
Specimen time	Kl. 10:20:49		
Start delay	7		
1 st pen time	-		
Specimen type	DRAENB06		
Water cont.	12,50		
Temperatur	20,00		
Humidity	60,00		
Fall type	FREE		
Time type	FIXED		
Final setting	NO		
Time	10,00		

ID	PEN [mm]	l [s]
1	0,0	7
2	0,0	17
3	0,2	27
4	0,1	37
5	0,2	47
6	0,0	57
7	0,1	67
8	0,2	77
9	0,0	87
10	0,0	97
11	0,2	107
12	0,1	117
13	0,0	127
14	0,2	137
15	0,2	147
16	0,2	157
17	0,0	167
18	0,1	177
19	0,2	187
20	0,0	197
21	0,1	207
22	0,2	217
23	0,0	227
24	8,0	237
25	7,0	247
26	20,8	257
27	20,0	267
28	19,8	277
29	21,1	287
30	28,6	297

ID	PEN [mm]	l [s]
31	32,8	307
32	35,1	317
33	34,2	327
34	35,0	337
35	36,3	347
36	38,7	357
37	38,5	367
38	37,3	377
39	38,2	387
40	40,7	397
41	39,9	407
42	40,7	417
43	40,5	427
44	40,6	437
45	40,5	447
46	41,2	457
47	40,9	467
48	41,4	477
49	41,8	487
50	41,9	497
51	41,9	507
52	41,3	517
53	41,9	527
54	41,6	537
55	41,8	547
56	41,5	557
57	41,4	567
58	41,3	577
59	41,3	587
60	40.9	597

ID	PEN [mm]	l [s]
61	40,7	607
62	40,9	617
63	41,6	627
64	41,3	637
65	42,1	647
66	42,1	657
67	42,0	667
68	42,7	677
<mark>69</mark>	42,0	687
70	41,1	697
71	41,1	707
72	41,9	717
73	42,1	727
74	41,6	737
75	41,4	747
76	41,4	757
77	41,3	767
78	41,2	777
79	41,6	787
80	41,4	797
81	42,1	807
82	41,8	817
83	41,5	827
84	41,8	837
85	42,2	847
86	42,6	857
87	41,60	867
88	42,30	877
89	41,20	887
90	41,60	897

0.25 M REF			
Test number	DRAEN6		
Kind of test	90 DROP		
Cycle tyoe	STANDARD		
Operator code	VS14		
Customer code	MSML14		
Date of test	27.05.2014		
Specimen time	Kl. 08:20:32		
Start delay	7		
1 st pen time	-		
Specimen type	DRAENB06		
Water cont.	13,10		
Temperatur	20,00		
Humidity	60,00		
Fall type	FREE		
Time type	FIXED		
Final setting	NO		
Time	10,00		

ID	PEN [mm]	l [s]
1	0,0	7
2	0,0	17
3	0,1	27
4	0,1	37
5	0,1	47
6	0,0	57
7	0,1	67
8	0,2	77
9	0,1	87
10	0,0	97
11	0,1	107
12	0,1	117
13	0,1	127
14	0,0	137
15	0,1	147
16	0,1	157
17	0,1	167
18	0,1	177
19	0,0	187
20	0,1	197
21	0,1	207
22	0,0	217
23	0,1	227
24	0,2	237
25	0,2	247
26	0,2	257
27	0,1	267
28	0,2	277
29	0,2	287
30	20,6	297

ID	PEN [mm]	l [s]
31	13,0	307
32	5,5	317
33	31,0	327
34	17,4	337
35	39,3	347
36	28,6	357
37	27,4	367
38	38,9	377
39	35,2	387
40	40,6	397
41	39,1	407
42	44,2	417
43	44,9	427
44	44,7	437
45	44,6	447
46	44,4	457
47	43,5	467
48	44,4	477
49	44,6	487
50	44,9	497
51	44,7	507
52	45,1	517
53	45,8	527
54	45,5	537
55	44,9	547
56	44, 6	557
57	45,1	567
58	45,5	577
59	44,9	587
60	44 5	597

ID	PEN [mm]	l [s]
61	44,2	607
62	44,5	617
63	44,8	627
64	45,2	637
65	45,5	647
66	45,7	657
67	45,1	667
68	45,1	677
69	45, 5	687
70	45,2	697
71	45 , 9	707
72	45,6	717
73	45,6	727
74	46,4	737
75	45,5	747
76	45,1	757
77	45,2	767
78	44,8	777
79	44,6	787
80	45,1	797
81	45,2	807
82	45,1	817
83	45,4	827
84	45,2	837
85	45 <mark>,</mark> 5	847
86	45,6	857
87	45,30	867
88	45,00	877
89	45,30	887
90	46,10	897
_		

0.50 M REF		
Test number	DRAEN6	
Kind of test	90 DROP	
Cycle tyoe	STANDARD	
Operator code	VS14	
Customer code	MSML14	
Date of test	06.05.2014	
Specimen time	Kl. 08:58:52	
Start delay	7	
1 st pen time	-	
Specimen type	DRAENB06	
Water cont.	13,80	
Temperatur	20,00	
Humidity	60,00	
Fall type	FREE	
Time type	FIXED	
Final setting	NO	
Time	10,00	

ID	PEN [mm]	l [s]
1	0,0	7
2	0,0	17
3	0,0	27
4	0,1	37
5	0,0	47
6	0,0	57
7	0,1	67
8	0,0	77
9	0,0	87
10	0,1	97
11	0,0	107
12	0,0	117
13	0,1	127
14	0,0	137
15	0,0	147
16	0,1	157
17	0,0	167
18	0,0	177
19	0,1	187
20	0,0	197
21	0,0	207
22	0,0	217
23	0,0	227
24	0,0	237
25	0,0	247
26	0,0	257
27	0,0	267
28	0,0	277
29	0,1	287
30	0,0	297

1	D	PEN [mm]	l [s]
3	31	0,0	307
З	32	0,1	317
3	33	0,0	327
3	34	0,0	337
3	35	0,1	347
З	86	0,0	357
3	37	0,0	367
3	88	0,0	377
3	39	0,0	387
4	10	0,0	397
4	1	4,4	407
4	2	3,1	417
4	3	14,1	427
4	4	13,2	437
4	15	20,3	447
4	6	20,4	457
4	17	30,3	467
4	8	21,6	477
4	9	31,3	487
5	50	31,3	497
5	51	29,7	507
5	52	30,9	517
5	53	33,7	527
5	54	33,8	537
5	55	34 , 9	547
5	56	35,5	557
5	57	35,5	567
5	58	34,8	577
5	59	31,1	587
e	50	36,5	597

ID	PEN [mm]	l [s]
61	30,8	607
62	31,0	617
63	31,7	627
64	32,2	637
65	31,8	647
66	34,2	657
67	34,2	667
68	32,8	677
69	33,6	687
70	38,0	697
71	37,8	707
72	38,0	717
73	31,4	727
74	38,0	737
75	39,8	747
76	37,2	757
77	35,3	767
78	35,6	777
79	34,7	787
80	35,7	797
81	37,2	807
82	37,3	817
83	36,2	827
84	37,7	837
85	37,8	847
86	39,4	857
87	39,7	867
88	37,8	877
89	38,1	887
90	38,6	897

1.00 M REF		
Test number	DRAEN6	
Kind of test	90 DROP	
Cycle tyoe	STANDARD	
Operator code	VS14	
Customer code	MSML14	
Date of test	07.05.2014	
Specimen time	Kl. 10:16:32	
Start delay	7	
1 st pen time	-	
Specimen type	DRAENB06	
Water cont.	15,30	
Temperatur	20,00	
Humidity	60,00	
Fall type	FREE	
Time type	FIXED	
Final setting	NO	
Time	10,00	

ID	PEN [mm]	l [s]
1	35,9	7
2	37,4	17
3	38,1	27
4	39,0	37
5	39,3	47
6	39,6	57
7	39,5	67
8	39,9	77
9	39,2	87
10	39,4	97
11	39,2	107
12	40,0	117
13	39,2	127
14	38,6	137
15	39,0	147
16	39,1	157
17	38,9	167
18	39,3	177
19	39,3	187
20	39,2	197
21	40,2	207
22	39,5	217
23	40,3	227
24	40,3	237
25	41,8	247
26	40,4	257
27	40,2	267
28	41,0	277
29	41,1	287
30	40,7	297

ID	PEN [mm]	l [s]
31	41,0	307
32	40,4	317
33	40,3	327
34	40,1	337
35	40,4	347
36	40,4	357
37	39,8	367
38	39,7	377
39	39,6	387
40	39,5	397
41	39,5	407
42	39,5	417
43	39,3	427
44	39,5	437
45	40,0	447
46	39,4	457
47	40,0	467
48	39,6	477
49	<mark>41,6</mark>	487
50	40,3	497
51	40,5	507
52	41,2	517
53	40,7	527
54	41,2	537
55	40,5	547
56	40,7	557
57	40,4	567
58	40,2	577
59	40,1	587
60	39,9	597

ID	PEN [mm]	[s]
61	39,6	607
62	40,2	617
63	39,3	627
64	39,6	637
65	39 , 5	647
66	39,0	657
67	40,1	667
68	39,5	677
69	39,2	687
70	40,4	697
71	40,7	707
72	41,1	717
73	40,8	727
74	40,2	737
75	40,0	747
76	39,8	757
77	39,3	767
78	39,5	777
79	39,0	787
80	39 , 5	797
81	40,6	807
82	39,1	817
83	41,7	827
84	41,1	837
85	40,2	847
86	40,5	857
87	40,1	867
88	39,7	877
89	40,0	887
90	39,8	897

0.10 M 5c		
Test number	DRAEN6	
Kind of test	90 DROP	
Cycle tyoe	STANDARD	
Operator code	VS14	
Customer code	MSML14	
Date of test	08.05.2014	
Specimen time	Kl. 08:15:33	
Start delay	7	
1 st pen time	-	
Specimen type	DRAENB06	
Water cont.	12,50	
Temperatur	20,00	
Humidity	60,00	
Fall type	FREE	
Time type	FIXED	
Final setting	NO	
Time	10,00	

ID	PEN [mm]	l [s]
1	0,1	7
2	0,0	17
3	0,1	27
4	0,0	37
5	0,1	47
6	0,0	57
7	0,0	67
8	0,1	77
9	0,0	87
10	0,0	97
11	0,0	107
12	0,0	117
13	0,0	127
14	0,0	137
15	0,0	147
16	0,0	157
17	0,0	167
18	0,0	177
19	0,1	187
20	0,0	197
21	0,1	207
22	0,1	217
23	0,0	227
24	0,0	237
25	2,1	247
26	7,6	257
27	9,0	267
28	29,8	277
29	36,2	287
30	36,2	297

ID	PEN [mm]	l [s]
31	39,2	307
32	41,1	317
33	40,0	327
34	40,5	337
35	42,3	347
36	40,2	357
37	42,6	367
38	40,9	377
39	40,7	387
40	41,0	397
41	42,6	407
42	41,8	417
43	42,1	427
44	42,4	437
45	42,9	447
46	42,6	457
47	42,9	467
48	44,4	477
49	43,4	487
50	44,8	497
51	43,9	507
52	43,7	517
53	43,8	527
54	44,0	537
55	44,6	547
56	45,1	557
57	45,1	567
58	44,9	577
59	44,3	587
60	43.8	597

ID	PEN [mm]	l [s]
61	44,1	607
62	43,4	617
63	43,6	627
64	44,5	637
65	42,8	647
66	43,4	657
67	43,7	667
68	44,6	677
69	44,3	687
70	44,2	697
71	44,6	707
72	43,8	717
73	44,6	727
74	45,2	737
75	44,9	747
76	45,0	757
77	44,2	767
78	44,1	777
79	44,0	787
80	44,6	797
81	43,8	807
82	44,3	817
83	44,2	827
84	44,5	837
85	44,8	847
86	44,0	857
87	44,5	867
88	44,5	877
89	43,8	887
90	44,2	897

0.25 M 5c		
Test number	DRAEN6	
Kind of test	90 DROP	
Cycle tyoe	STANDARD	
Operator code	VS14	
Customer code	MSML14	
Date of test	28.05.2014	
Specimen time	Kl. 08:15:09	
Start delay	7	
1 st pen time	-	
Specimen type	DRAENB06	
Water cont.	12,50	
Temperatur	20,00	
Humidity	60,00	
Fall type	FREE	
Time type	FIXED	
Final setting	NO	
Time	10,00	

ID	PEN [mm]	l [s]
1	0,1	7
2	0,1	17
3	0,2	27
4	0,1	37
5	0,1	47
6	0,0	57
7	0,1	67
8	0,1	77
9	0,1	87
10	0,2	97
11	0,1	107
12	0,0	117
13	0,0	127
14	0,1	137
15	0,1	147
16	0,1	157
17	0,2	167
18	0,1	177
19	0,2	187
20	0,1	197
21	0,1	207
22	0,2	217
23	0,2	227
24	0,2	237
25	0,0	247
26	0,0	257
27	0,6	267
28	0,1	277
29	0,1	287
30	0,2	297
	,	

ID	PEN [mm]	l [s]
31	18,7	307
32	21,6	317
33	30,3	327
34	17,0	337
35	38,9	347
36	39,7	357
37	36,0	367
38	29,2	377
39	35,4	387
40	34,1	397
41	35,1	407
42	37,2	417
43	39,6	427
44	36,9	437
45	39,5	447
46	39,6	457
47	40,8	467
48	40,5	477
49	40,8	487
50	41,1	497
51	41,0	507
52	42,4	517
53	41,6	527
54	41,9	537
55	41,7	547
56	41,5	557
57	41,7	567
58	40,2	577
59	42,2	587
60	42.5	597

ID	PEN [mm]	[s]
61	41,9	607
62	43,1	617
63	41,5	627
64	42,0	637
65	41,9	647
66	42,0	657
67	42,2	667
68	41,5	677
69	42,2	687
70	43,1	697
71	42,0	707
72	42,2	717
73	42,4	727
74	42,3	737
75	42,6	747
76	42,4	757
77	43,1	767
78	42,4	777
79	42,4	787
80	42,6	797
81	42,3	807
82	42,1	817
83	42,4	827
84	42,6	837
85	42,6	847
86	42,7	857
87	42,4	867
88	42,7	877
89	42,4	887
90	42,6	897
0.50 M REF		
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Test number	DRAEN6	
Kind of test	90 DROP	
Cycle tyoe	STANDARD	
Operator code	VS14	
Customer code	MSML14	
Date of test	09.05.2014	
Specimen time	Kl. 09:21:03	
Start delay	7	
1 st pen time	-	
Specimen type	DRAENB06	
Water cont.	13,80	
Temperatur	20,00	
Humidity	60,00	
Fall type	FREE	
Time type	FIXED	
Final setting	NO	
Time	10,00	

ID	PEN [mm]	l [s]
1	0,0	7
2	0,0	17
3	0,0	27
4	0,0	37
5	0,0	47
6	0,0	57
7	0,0	67
8	0,0	77
9	0,1	87
10	0,0	97
11	0,0	107
12	0,0	117
13	0,0	127
14	0,0	137
15	0,1	147
16	0,0	157
17	0,0	167
18	0,0	177
19	0,0	187
20	0,0	197
21	0,0	207
22	0,0	217
23	0,0	227
24	0,0	237
25	0,0	247
26	0,0	257
27	0,0	267
28	0,0	277
29	23,8	287
30	6,0	297

ID	PEN [mm]	[s]
31	0,0	307
32	20,3	317
33	37,1	327
34	29,4	337
35	29,6	347
36	28,6	357
37	34,9	367
38	36,6	377
39	36,5	387
40	40,1	397
41	36,8	407
42	41,4	417
43	36,0	427
44	36,5	437
45	38,8	447
46	42,1	457
47	38,8	467
48	42,3	477
49	38,8	487
50	45,5	497
51	45,1	507
52	46,7	517
53	45,8	527
54	46,1	537
55	46,6	547
56	43,4	557
57	45,1	567
58	44,9	577
59	45,0	587
60	45,1	597

ID	PEN [mm]	l [s]
61	45,8	607
62	45,5	617
63	45,8	627
64	45,6	637
65	45,6	647
66	45,3	657
67	44,9	667
68	45,2	677
69	45,1	687
70	46,4	697
71	46,4	707
72	46,3	717
73	46,8	727
74	46,1	737
75	45,7	747
76	45,5	757
77	45,6	767
78	45,7	777
79	45,8	787
80	45,8	797
81	45,1	807
82	45,7	817
83	45,3	827
84	45,8	837
85	46,0	847
86	46,4	857
87	45,8	867
88	45,5	877
89	45,7	887
90	45,7	897

1.00 M REF		
Test number	DRAEN6	
Kind of test	90 DROP	
Cycle tyoe	STANDARD	
Operator code	VS14	
Customer code	MSML14	
Date of test	12.05.2014	
Specimen time	Kl. 14:42:06	
Start delay	7	
1 st pen time	-	
Specimen type	DRAENB06	
Water cont.	15,30	
Temperatur	20,00	
Humidity	60,00	
Fall type	FREE	
Time type	FIXED	
Final setting	NO	
Time	10,00	

ID	PEN [mm]	l [s]
1	0,1	7
2	39,6	17
3	40,1	27
4	24,2	37
5	39,8	47
6	39,6	57
7	39,3	67
8	40,8	77
9	39,4	87
10	38,7	97
11	38,4	107
12	39,9	117
13	39,8	127
14	40,5	137
15	40,5	147
16	39,6	157
17	39,4	167
18	40,2	177
19	41	187
20	41,6	197
21	40,4	207
22	40,3	217
23	40,5	227
24	41	237
25	41,3	247
26	41,4	257
27	41,1	267
28	42	277
29	44,8	287
30	42	297

ID	PEN [mm]	l [s]
31	42,4	307
32	41,6	317
33	41,7	327
34	41	337
35	41,7	347
36	42,6	357
37	39,8	367
38	40,9	377
39	40,8	387
40	40,4	397
41	39,9	407
42	40	417
43	41	427
44	40	437
45	40,9	447
46	40,7	457
47	40,9	467
48	41	477
49	41,2	487
50	40,5	497
51	40,7	507
52	41,4	517
53	41	527
54	41,7	537
55	41,7	547
56	41,4	557
57	42	567
58	40,7	577
59	41,4	587
60	43.3	597

ID	PEN [mm]	l [s]
61	40	607
62	41,4	617
63	40,1	627
64	41,2	637
65	40,4	647
66	39,9	657
67	39,9	667
68	41	677
69	40,9	687
70	40,6	697
71	42,2	707
72	40,8	717
73	42,6	727
74	41,4	737
75	41,4	747
76	41,3	757
77	40,4	767
78	41,1	777
79	40,1	787
80	40,3	797
81	40,8	807
82	40,3	817
83	40,5	827
84	40,7	837
85	40,8	847
86	41,7	857
87	40,3	867
88	40,5	877
89	41,3	887
90	40,7	897