Technical University of Denmark

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Crushed concrete as recycled aggregates

Bachelor project

January 2018

DTU Civil Engineering
Department of Civil Engineering

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PREFACE

This report is the result of a bachelor project worth 15 ETCS points. It has run over a period spanning from September the 4. 2017 to January the 5. 2018. It has been developed under the supervision of the DTU Civil Engineering department at the Technical University of Denmark.

Special thanks to the primary supervisors Lisbeth M. Ottosen and Gunvor Marie Kirkelund, for continuous feedback during the project. Thanks, to Ebba C. Schnell, for guiding and teaching vital experiments in the laboratory, and Louise Green Pedersen for her guidance and experience relating to the tests.

Special thanks to Kurt Kielsgaard Hansen for providing the E-modulus apparatus and helping understand the output data, and Marianne Tange Hasholt and Per Goltermann for explaining the theoretical principles behind the tests.

An enormous thanks to Klaus Bræmer and Per Leth the heroes of the workshop, always ready to advise and assist in making and handling of the concrete tests.

The report it made along alongside Signe Bjerrum, with whom many of the experiment were made, and Nanna Johnsøn who worked with her master thesis alongside us, and with whom much of the theory was discussed.

TANYAS VARGAS BECERRA (S143923)

ABSTRACT

An interest in green, and sustainable technologies is highly relevant these days as phenomena such as global warming is affecting the planet. Any part of a process that can become greener, without creating too many downsides should do so. In the construction business this translates to an interest about the ability to recycle concrete using aggregates, otherwise known as RCA. Debris used from the torn down tunnel between buildings 118, and 119 at DTU has provided a useful opportunity to investigate this idea.

The aim becomes figuring out how the strength, and elasticity of the concrete are affected, as well as the overall characteristics, and properties of the final recycled RCA concrete. Furthermore, the objective is to consider the usability of raw state materials. Raw state meaning without having been washed, dried or otherwise processed.

A reference batch of 0% recycled concrete and batches of concrete where 15%, 25%, 30%, 50% , 75% and 100% of the coarse aggregates were replaced with the corresponding RCA fraction were studied with a focus on aggregates of size 4-8mm and 8-16mm.

All batches follow the same recipe structure to ensure compatibility. The water-cement ratio used is 0.6. All tests are done after 7 days of curing. All aggregates used are utilized in the state they originally were found in, and this is accounted for, rather than changing the state. This is done in the hopes of evaluating their usability for construction work, to ease handling.

The absorption, LA coefficient, water content, cement paste content and density are determined for the RCA. The compressive strength, porosity, density and E-modulus for the concrete is also found.

The results of these experiment lead to finding that the absorption of the RCA could not be determined properly. Density was found to decrease with the increase in RCA replacement. The compressive strength is lower for all RCA containing tests compared to the reference tests, but the 50% replacement of coarse aggregates with RCA is the strongest of the RCA replaced tests. The elasticity was difficult to determine, but the results indicate that the replacement rates under 50% are the more elastic overall.

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1 INDHOLD

1 INTRODUCTION

Concrete is currently the main material used in Denmark's construction world. Easy usage, low price, dependability and endurance supports its popularity within the industry. At current time the aggregates used in production of concrete are mainly stones retrieved from the water floor, dug from the soil or produced by crushing boulders.

With these resources not being fully recycled, it is relevant to consider a greener use of aggregate production. The focus of this project is to look at the reuse of concrete in the production of new concrete. It is a popular interest, which already has strong roots in Holland.

Debris from the torn down tunnel between building 118 and 119 at DTU has provided the opportunity to investigate the properties of concrete using recycled concrete aggregates. The tunnel was tightly placed between the two buildings and it was therefore not possible to crush the concrete by normal means. The concrete waste was therefore torn down by hand and placed into barrels. It is from this point of the process the project took over the materials. The focus is the replacement of recycled concrete aggregates in the sizes 4-8mm and 8-16mm. Equal amounts of the RCA is replaced each time, with a water cement ratio of 0.6. All tests are done after 7 days of curing. All aggregates are utilized in the state they originally were found in, and this is accounted for in the recipe. This is done in the hopes of confirming aggregate usability in construction work.

Initial focus of the project is the aggregates and their properties. This is required by the new upcoming Danish standards DS/EN 206-1 DK NA, which requires information on the recycled concretes properties such as density, absorption and cement paste content. These properties are further expanded on by finding the water content, grain distribution curve and Los Angeles coefficient.

This leads to investigating the new concrete which includes mixing recipe, slump, air content, compressive strength and Young's modulus. These factors help evaluate the finished RCA based concrete to see how the different parameters change the outcome.

1.1 THE OBJECTIVE

The aim of this report is to study the effects of adding RCA on the strength and elasticity of the concrete, as well as examine the properties and characteristics of the recycled concrete.

Furthermore, the objective is to consider the usability of raw state materials. Raw state meaning without having been washed, dried or otherwise processed.

2 THEORY

2.1 CONCRETE

Concrete is the most used construction material in Denmark, and is produced by a combination of materials, which is illustrated in figure 2-1.

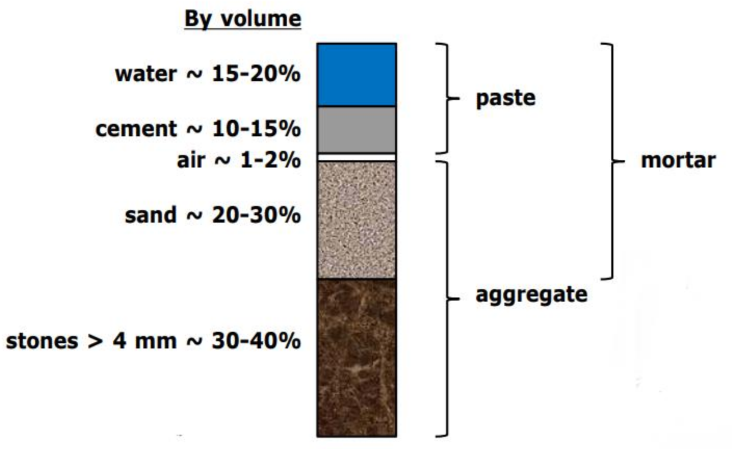


Figure 2-1 concrete constituents and terminology (Hasholt 2017)

There are a large variety of mixtures all of which contain different ratios of the materials. Some promote a higher resistance to low temperatures, while others may be optimised for underwater conditions. The concrete tested in this report is a simple mix of basic constituents, which will ensure more controllable parameters.

2.1.1 Water-cement ratio

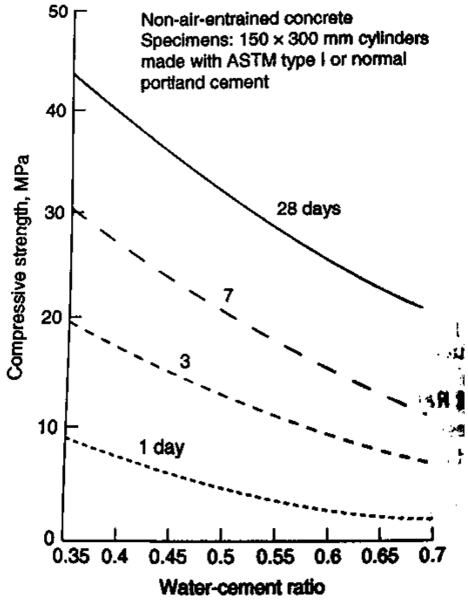


Figure 2-2 change in compressive strength as w/c-ratio changes (Mehta and Monteiro 2014)

While making a concrete mix, it is important to be aware of the water-cement ratio (w/c ratio). This ratio has a substantial influence on the strength of the final concrete. Cement production has a large CO_2 release which makes it undesirable in copious quantities, as it will have a negative impact on the products CO_2 footprint. Concrete is used for a large variety of products, including ones that are not just simply buildings, so low compressive strength is also sought after. Increasing the w/c ratio will help improve the sustainability of the product, as less cement is used. Figure 2-2 illustrates the decrease in compressive strength as the w/c-ratio increases.

2.1.2 Aggregates

The aggregates are divided into categories; those of size 0-4mm are referred to as sand, where all above 4mm are classified as coarse aggregates. The project only makes use of coarse aggregates in the categories 4-8mm and 8-16mm. The workshop provides natural marine aggregates (NA) in form of both marine sand and marine stones, which are all provided by the company NNC.

4-8mm 8-16mm

Figure 2-3 Marine stones form the workshop

2.1.3 Particle distribution curve

The distribution curve illustrates the distribution of particle sizes within an aggregate category. This can be used to indicate how homogeneous the sample is. An interval of particle sizes that is significant will be represented with a steep curve. A straight line from 0 to 100% would indicate a completely homogenous distribution.

2.1.4 Los Angeles abrasion

When working with a material it is convenient to know its abrasion characteristics. The Los Angeles abrasion test (LA test), is set up to better quantify a material's toughness. A porous material is more likely to crumble during handling, which can lead to changes in the particle sizes. The test is experimental, and does not relate directly to practical use. However, performing the LA test on RCA and NA should yield an indication of their compared characteristics. It is expected that the RCA with highest cement paste content will likely have the highest LA coefficient of the RCAs, as mortar is more porous than stone. The same logic is applicable when comparing the RCA and NA, as it is expected that the RCAs will have a higher LA coefficient than the NA, because there is no mortar on the NA.

2.1.5 Water absorption

All materials have a certain degree of water absorption. Depending on the sample this can greatly affect the amount of water added to a mix to gain the correct w/c ratio. There is no sufficient way of determining this parameter accurately. A lower absorption is easier to work with, as it will not take as much water from the w/c ratio. If a high quantity of a highly absorbent material is added to a mix, the uncertainty of the absorption test is more clearly noticed as more NA is replaced with RCA.

2.1.6 Cement paste content

When compressing a concrete cylinder, cracks will form on the shortest distance between coarse aggregates, as these are much stronger than the cement paste. As the test concrete will contain varying amounts of RCA, is it relevant to investigate the amount of cement paste that is contained in each coarse aggregate category. This will determine how big a percentage of the RCA is paste and how much is stone, as it is expected that with an increasing amount of RCA replacement the increasing amount of paste will weaken the cylinder.

2.1.7 Pycnometer tests

One of the important properties to know about the materials used in the recipe is the density. This property helps convert volume to mass. The pycnometer test is also being used to find the absorption, though this method is frowned upon for its inaccuracy. However, only more uncertain methods are available.

2.2 MIXTURE RECIPE

For the mixture recipe the recipe from Dansk Betonforening (2013) is followed. This is based off the wide range of parameters such as water content, absorption and density. This ensures a more accurate proportioning of the concrete constituents.

2.2.1 Slump

Before the wet mix concrete is placed into its casts, the slump is measured. This indicates the liquidity of the wet mix, and is a measure of how workable the mix is. On the construction site a wetter mix is desired as it is easier to apply and does not require much vibration, which is used to settle the material. The wet mix is vibrated using a specially designed table, see figure 3-9.

2.3 COMPRESSIVE STRENGTH

The compressive strength test is used both for determining the E-modulus as well as comparing the strengths of the concrete samples. It is expected that the samples will lose strength compared to the reference samples as the amount of RCA is increased. This would follow the same principles as mentioned in 2.1.6.

2.3.1 Bolomey's formula

To theoretically predict the strength of concrete Bolomey's formula can be used. It works within the limitations of $0.45 < \frac{w}{c} < 1.25$ and a natural air content that does not surpass 1.5-2.0% (Wøhlk-Poulsen 2011).

$$f_c = k\left(\frac{1}{w/c} - m\right) \tag{2.1}$$

Where:

f_c: Compressive strength [MPa]

k: Cement type specific coefficient [-]

w/c: Water cement ratio [-]

m: a constant [-]

Table 2-1 K-value determined by cement type (Hansen 2008)

Aalborgs Portlands betegnelser	Cementnormbetegnelser efter DS/EN 197-1	K [MPa]
Basis®	II/A-LL 52,5R	32
ABC®	II/A-LL 52,5N	28
Rapid®	I 52,5N	31
Lavalkali sulfatbestandig	I 42,5N	26
Hvid	I 52,5N	32

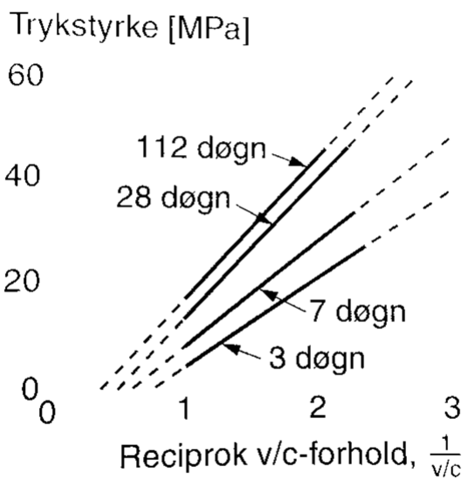
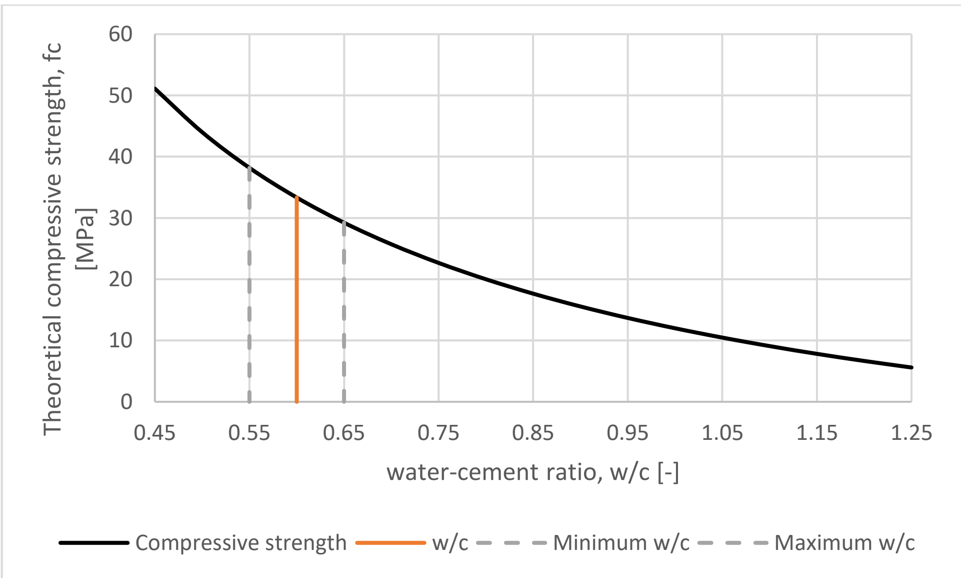


Figure 2-4 Bolomeys formula (Hansen 2008)

The K-value is determined by the cement type and is found in Table 2-1. The m-constant is determined by the x-intercept on figure 2-4 for seven days.



Graph 2-1 The w/c-ratio of this projects intercept with Bolomey's formula

The theoretical expected compressive strength is therefore:

$$f_c = 33 \pm 4.5\ MPa$$

The variation is considering the possible uncertainties of the mixing recipe and human error.

2.4 Porosity

If there is a high concentration of air in the cement, it will weaken if not compensated for. It is therefore important to test. There are two methods, one is using the pore size distribution meter, the other is through tests involving weight.

The first test is using an apparatus and is further explained in the method and materials section.

For the second test, the mass of each cylinder is found in the mediums air, m, and water, m_w. To find the volume of air the following formula has been deduced:

$$V_{air} = \frac{m - m_w}{\rho_w} - V_{blanding} \tag{2.2}$$

Where:

V_{air}: Volume of air in the cylinder [m^3]

m: mass [kg]

m_w: mass below water [kg]

ρ_w: Density of water [kg/m^3]

$V_{blanding}$: calculated expected volume without air from mixing recipe [m^3]

This is further used to find the air content:

$$Air\ content = \frac{V_{air}}{V_{cyl,measured}} \tag{2.3}$$

Where:

$V_{cyl,measured}$: Volume of the hand measure cylinder [m^3]

The weight based result is expected to possibly be negative as the densities of the aggregates have an uncertainty of $\pm 40 \frac{kg}{m^3}$ $(\ sourse\ the\ shipping\ info)$. This uncertainty is expected to be even higher for the RCA.

2.5 STRAIN CURVE

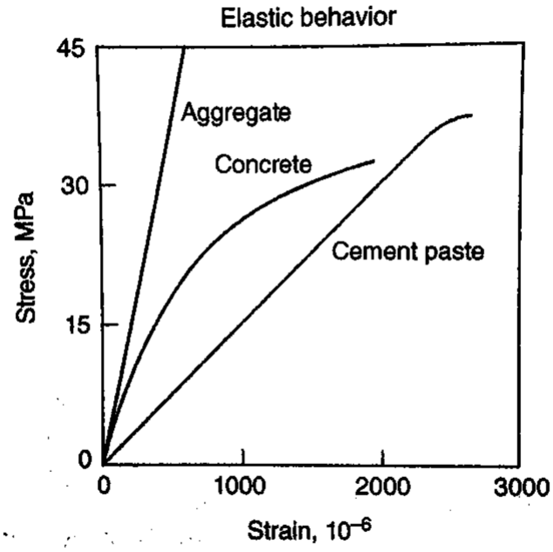


Figure 2-5 – Strain curve for cement mortar, concrete and aggregates (Mehta and Monteiro 2014)

When compressing a material, the force applied and deformation at corresponding times will form a strain curve. The horizontal axis plots the strain and the vertical axis is the stress. This curve is different depending on the material. For concrete the strain curve tends to be curvy.

2.6 YOUNG'S MODULUS

Young's modulus is named after the English physician and physicist Thomas Young[1], and is also referred to as the elasticity modulus or E-modulus. It is a proportionality factor between the stress and strain of a material, and indicates the elasticity of the material. As the elasticity modulus is the slope of the tangent found at the beginning of the strain curve, the formula for the E-modulus will look as following:

$$E = \frac{\sigma}{\varepsilon} = \frac{\frac{F}{A}}{\frac{\Delta L}{L_0}} = \frac{FL_0}{A(L - L_0)} \tag{2.4}$$

Where:

E: Elasticity modulus [GPa]

σ: Stress [kN/m^2]

ε: Strain [-]

[1] https://www.britannica.com/science/Youngs-modulus

F: Force [MPa]

A: Cross sectional area [m^2]

L_0: Initial length of material [m]

L: Length of material [m]

Concrete has a strain curve which was discussed in section 2.5. Here it is deduced that a strain curve for the RCA concrete will appear straighter due to the much higher cement paste content. This gives a lower E-modulus, which theoretically will decrease with the increased replacement percentage of RCA.

3 METHOD AND MATERIALS

3.1 RECYCLED CONCRETE AGGREGATES

In 2017, Danish Technical University were undergoing reconstruction of a testing facility on their Lyngby, Denmark campus. During this a tunnel, from the original 70's build, was torn down. The tunnel was made from standard grade concrete with granite stones for coarse aggregates. This concrete is what in this report is referred to as recycled concrete aggregates (RCA).

4-8mm 8-16mm

Figure 3-1 samples of the RCA

3.2 CRUSHING OF THE RCA

The available machinery at the DTU testing facility can crush concrete into the desired size of 0 to 16mm, where the maximum size that can be processed lies at around 4-5cm.

If materials received from the construction site are concrete chunks in sizes of above 5cm in diameter, it is required that the blocks are reduced in size. This will not typically pose an issue, as it is common for construction sites to process the torn down concrete through an onsite crusher. This crusher reduces the concrete rubble into aggregates of the size typically required for reuse as recycled concrete.

Figure 3-2 Vice with triangular beaks and crushing machine from Buch and Holm

The main pieces are crushed into smaller chunks of approximately 4-5 cm in diameter, using a vice with triangular beaks, see figure 3-2. These newly produced fragments are then processed by the onsite crusher, produced by Buch and Holm. The crusher has settings from 0-5.5, increasing in halves. The setting 5 is used to crush the fragments into aggregates. Once a few buckets of the aggregates are collected, the sorting of material can begin.

3.3 SIEVING

Figure 3-3 Endecott test sieving shaker and sieves

A 10kg sample of the RCA, before sorting, is collected and dried in an oven at 105 degrees Celsius for a period of 24 hours, until completely dry. Endecott, a test sieving shaker machine, is then used to sieve the material into six sections; 0-1mm, 1-2mm, 2-4mm, 8-16mm, 16-32mm and 32+mm. Sieving 1.5 kg at a time will prevent the material from stacking within the section separators, allowing for more efficient sorting. The sections are weighed individually before sorting. After each sieving, the sections are weighed again with sieving content included, and the fraction of each are recorded. This is used to find the Particle Distribution Curve.

3.4 PYCNOMETER TESTS

Figure 3-4 Vacuum containers for the pycnometer test (Herløv 2017)

Three times 200g of each RCA is placed in containers with sterilized water. The pycnometer then extracts all air from the system using vacuum environments, and after approximately 24 hours the container is removed and filled with sterilized water. A special lid ensures only a uniform volume of substance is allowed within the container when closed. The weight of the container with and without content is recorded, and the density calculated.

The fully saturated aggregates are then dried with paper napkins to a state, which appears to be saturated surface dry, also known as s.s.d.-state. They are then weighed again. The equation (Gottfredsen and Nielsen 2015) indicates the absorption in form of the relationship between the water mass and dry mass:

$$w_a = \frac{m_{ssd} - m_d}{m_d} * 100 \tag{3.2}$$

Where:

w_a: Absorption [%]

m_{ssd}: mass in ssd-state [kg]

m_d: dry mass [kg]

3.5 WATER CONTENT

Initially, 300g of each material is weighed off and placed in an oven at 105°C for minimum 24 hours. They are then weighed again, and the difference in mass indicates the water content. The equation indicates the water content in form of the relationship between the water mass and dry mass:

$$w = \frac{m_w - m_d}{m_d} * 100 \tag{3.3}$$

Where:

w: Water content [kg]

m_w: mass before drying [kg]

This follows the Danish standard DS/EN 1097-5.

3.6 CEMENT CONTENT

By weighing off 3 dried samples of each of the aggregates and then subjecting them to a cocktail of water and nitric acid (HNO_3), the nitric acid will then react, effectively removing the cement paste from the RCA samples.

Three samples of both 4-8mm and 8-16mm RCA are dried at 105°C for 24 hours in an oven. It is important to repeat that the nitric acid only reacted with the cement, thus other materials which may have found their way into the concrete mix other than cement, water, aggregates and sand, will now reveal themselves. 17ml of nitric acid is mixed in a measuring flask (1L) which is half full of desterilised water. It is shaken well, and the flask is filled to 1L with more desterilised water.

Figure 3-5 RCA in the acid bath while fuzzing

Each sample is placed in a laboratory flask with enough of the nitric-water mix added to sufficiently cover the RCA. A small amount of the acid, 5ml for 4-8mm RCA and 10ml for 8-16mm RCA, is then continuously added over time until there ceases to appear any (or only very few) air bubbles in the liquid, see figure 3-5.

Table 3-1 dosage guide to cement paste content test

Sample	Sample size	HNO3 initially added	HNO3 doses continuously added
	g	ml	Ml
4-8mm RCA	20	17	5
8-16mm RCA	50	17	10

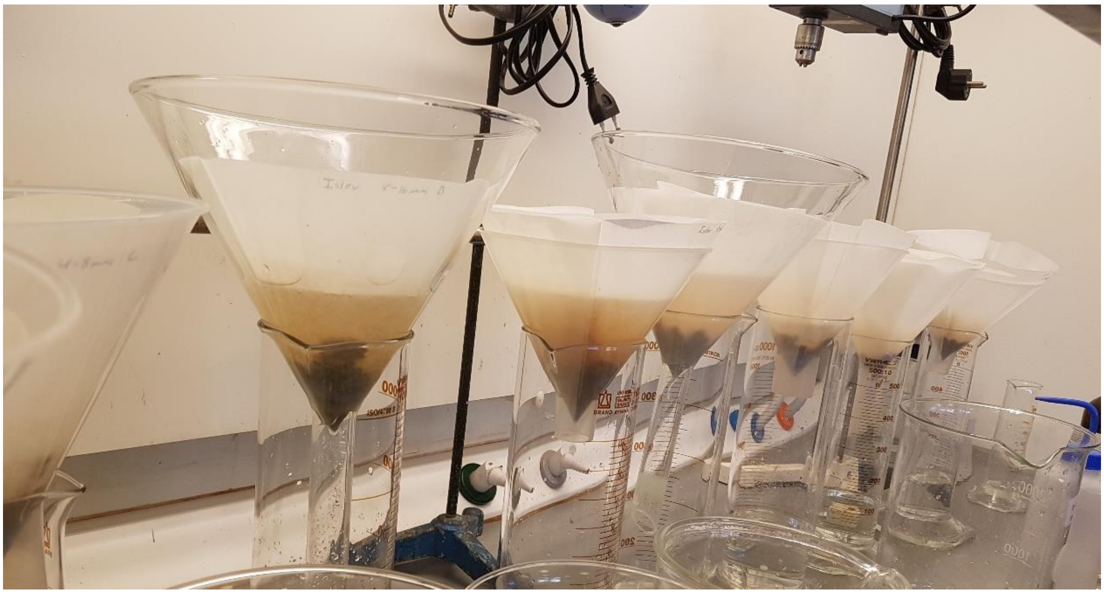


Figure 3-6 RCA tests in filters

The content can now be filtered into a conical flask using weighed filters, which is then left until there is no more dripping observed from the filter, see figure 3-6. The filters are then placed in petri dishes and placed in an oven at 105°C for at least 24 hours. The difference in mass found from the RCA sample and the cement paste free sample indicates the cement paste content:

$$Cement\ paste\ content\ [\%] = \frac{m_{dry,RCA} - m_{paste\ free}}{m_{dry,RCA}} * 100 \qquad (3.4)$$

Where:

$m_{dry,RCA}$. Dry RCA mass [kg]

$m_{paste\ free}$: cement paste free mass [kg]

3.7 LOS ANGELES ABRASION

Figure 3-7 LA abrasion testing machine

The standard for the Los Angeles abrasion test follows the DS EN 1097-2 standard. Firstly 2 samples of 1.5kg are collected from each of the following categories 4-8mm RCA, 8-16mm RCA, 4-8mm NA and 8-16mm NA. All samples must be dried in an oven at 105°C for 24 hours. A LA test machine is used, see figure 3-7. The drum is filled with a test sample and the number of steel balls required for the sample is inserted. The number of balls is determined using table 3-2, and are used to crush the aggregates in a controllable manner.

Table 3-2 guide to classifications in the LA abrasion test (EN 1097-2)

Range classification mm	Intermediate sieve size mm	Percentage passing intermediate sieve %	Number of balls	Mass of ball load g
4 to 6,3	5	30 to 40	7	2 930 to 3 100
4 to 8	6,3	60 to 70	8	3 410 to 3 540
6,3 to 10	8	30 to 40	9	3 840 to 3 980
8 to 11,2	10	60 to 70	10	4 250 to 4 420
11,2 to 16	14	60 to 70	12	5 120 to 5 300

For this test, 8 balls are chosen for the 4-8mm samples and 12 balls are inserted for the 8-16mm samples. The drum is set to 500 rotations, with 30 rotations per minute. When the machine is done, the sample is sieved though a 1.4mm sieve and weighed. The following formula is used to find the LA abrasion loss[2] coefficient:

$$LA = \frac{m_i - m_a}{m_i} * 100 \tag{3.5}$$

Where

LA: Los Angeles coefficient [%]

m_i: Initial dry sample mass [kg]

m_a: Mass with particles below 1.4mm [kg]

3.8 CASTING AND CURLING

The mix is made by adding the dry aggregates and cement into the mixer for 2 minutes, and then adding the water, to increase the possibility of homogeneous behaviour. The mix then rotates for 5-7 minutes. A slump test is then made, where the slump is found following the procedure explained and illustrated in figure 3-8.

[2] Method send by louise

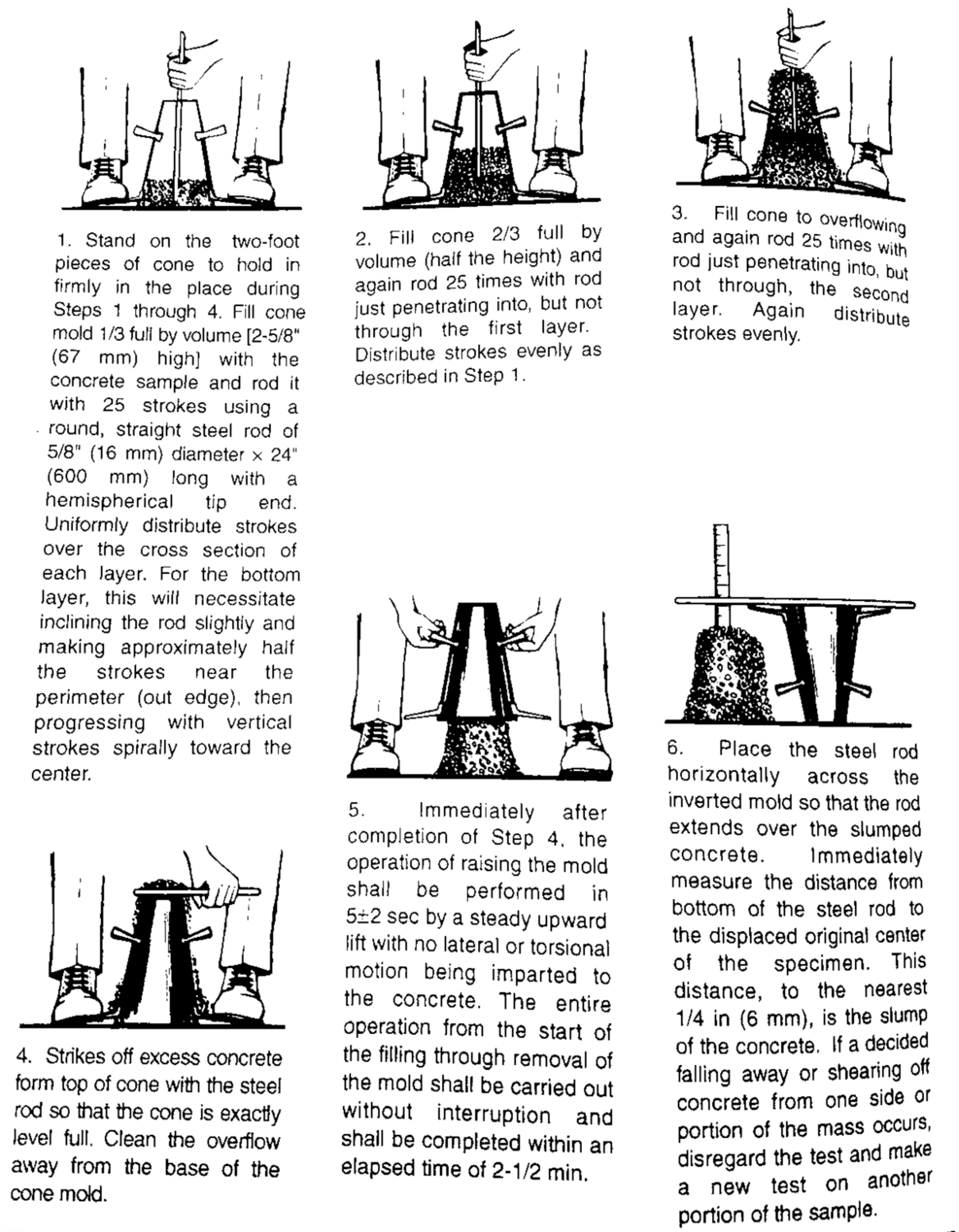


Figure 3-8 Guideline for performing the slump test (Mehta and Monteiro 2014)

The wet concrete mix is cast into minimum 4 casts of cylindrical shape, with a diameter of 100mm and a height of 200mm. This is done by filling a third of the cast at a time, while it sits on a vibrating table, see figure 3-9. A wetter mix will require less vibrating as the aggregates will fall to the bottom, while a drier mix can handle more. Load the cast until a there is a top, and slowly slide the lid into place, by running it in a zig-zag movement to best allow the wet concrete to settle. A clamp is then used to secure each lid on tightly. Excessive wet mix is not washed off, as it may compromise the mix in the cast.

The casts are left to set for 24 hours and are then removed. The cylindrical concrete samples are then placed into water for 6 days, after which testing can take place, see figure 3-11.

Figure 3-9 Vibration table in workshop

Figure 3-10 D100 H200 cylinders from workshop

Figure 3-11 Water basing for test to curl in

3.9 POROSITY

3.9.1 Pore size distribution apparatus

Figure 3-12 Apparatus to access air content in wet concrete

The wet concrete mix is filled into the container, see figure 3-12. It is vibrated during the loading to let it settle. Filling it to the rim and then cleaning the sides which connects the lid and container, ensures a tight fit. The lid is then placed straight on top and the red marks are aligned.

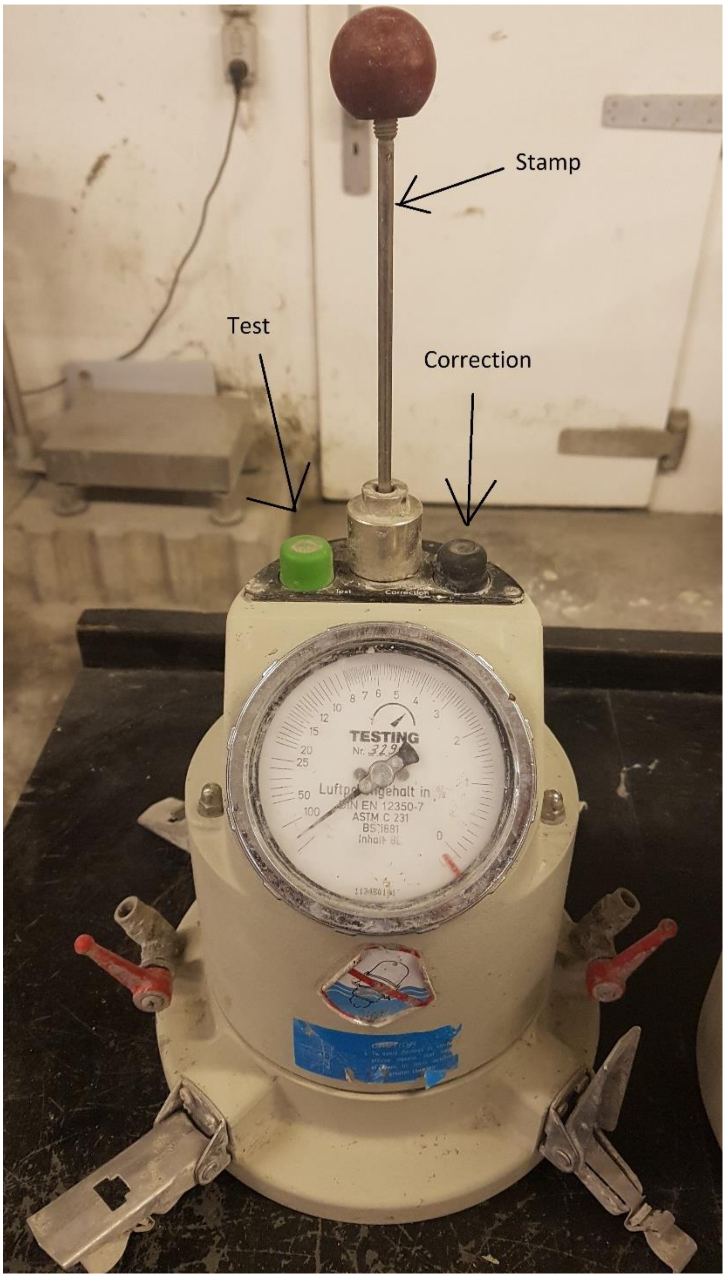


Figure 3-13 air content apparatus with terminology indicators

Water is sprayed into the container through one of the side tubes and the opposite tube is shut when water starts flowing out the opposite end. The first tube is then also shut while still adding water to the container. The stamp is then pumped until the arm on the meter is below 0, see figure 3-13. Tapping the glass may help adjust the arm. The black button is then used until the arm is on the red mark. The green button is then pressed until the arm stops moving, and the air content percentage can be noted.

3.9.2 Weight based

Figure 3-14 Set up in workshop to weight the cylinders above and below water

The concrete cylinder is weighed earliest possible after casting, which translates to approximately 12 hours. It is weighed both above water and below water, see figure 3-14. Equations 2-2 and 2-3, from the theory section 2.4, is used.

3.10 PRESSURE TEST

7 days after casting the test cylinders are extracted from the water basin where they have been curing. Each cylinder's diameter is measured 3 times to account for human error. This means that the average value will be used. The same method is used for the height. The weight is measured on a scale. These values are inserted into the Toni 3000, the machine that measures the compressive strength. The following standard values are used:

$$df/_{dt} = 4.71kN/s$$

$$Load\% = 5.00$$

The compressive strength given by the machine is in kN. The displayed measurements within the interval 30-900kN may vary from the true value with maximum 0.6%.[3]

3.10.1 Youngs modulus test

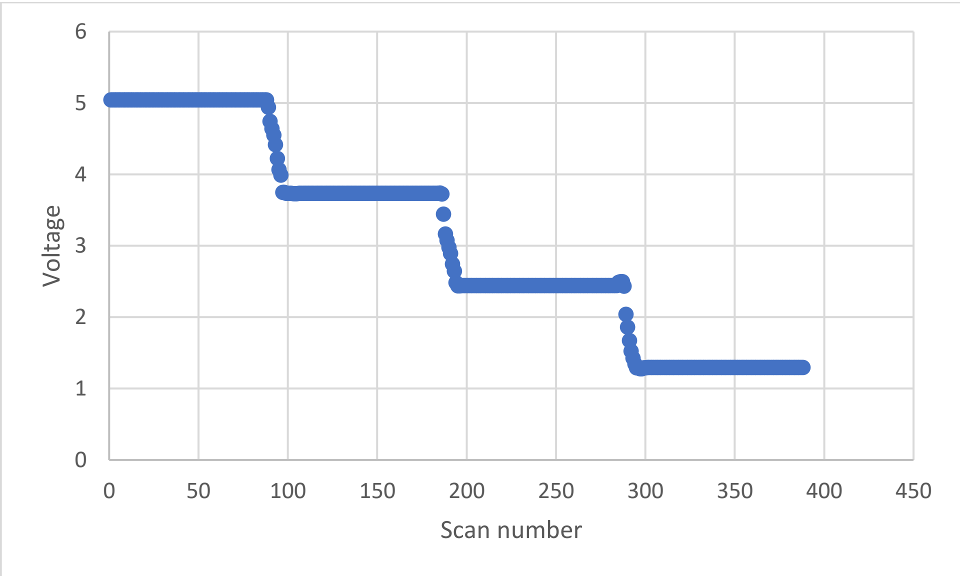
Figure 3-15 E-modulus apparatus

Figure 3-16 The Data Logger (left) and the ruler used for calibration (right)

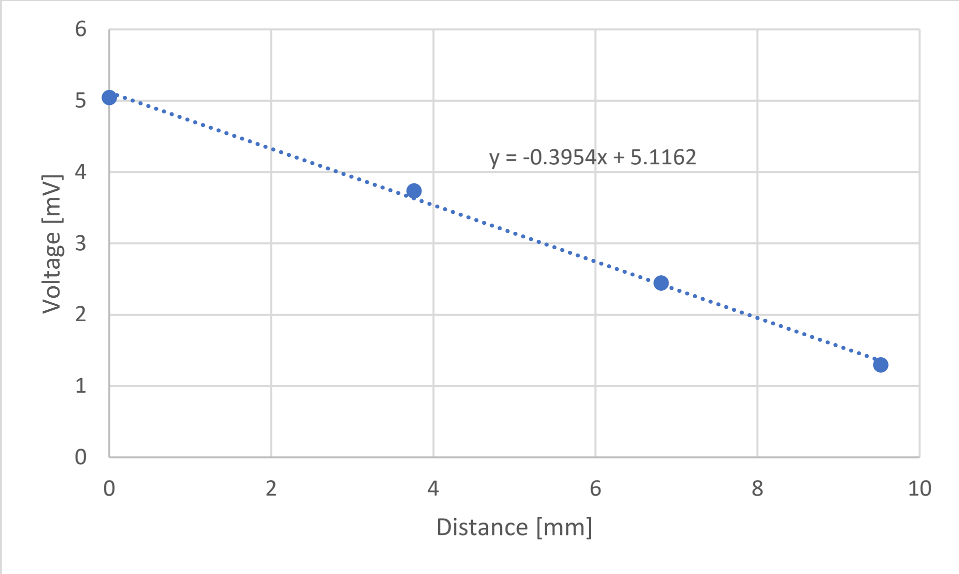
[3] Tested by Brian Burmeister, disclaimer on machine

A E-modulus measuring device is attached to the cylinder in two pieces. They both have legs which standardizes the devices placement on the cylinders, see figure 3-15 and 3-17. The legs are then removed so that the cylinder can be compressed. The sensors attached to the device then records the displacement of the upper piece of the device in respect to the lower piece. This is then recorded on an Agilent Data Logger Switch Unit, alongside the overall displacement and load of the machine.

The measuring device has been calibrated prior to testing on both sensors. This is done by measuring four known distances, see figure 3-16 (right), and recording it on the Data Logger, see graph 3-1. Excel is then used to draw a trendline between the four points to make a conversion equation, see graph 3-2, which is used to convert the output from mV to mm.



Graph 3-1 Raw output data from the calibration



Graph 3-2 Processed calibration data

The device is only allowed to record the first 40% of the load compression, to ensure the safety of the mechanics. This means that the first test of the batch cannot be used to find the E-modulus as a pressure test is needed to find the approximate compressive strength of the sample batch.

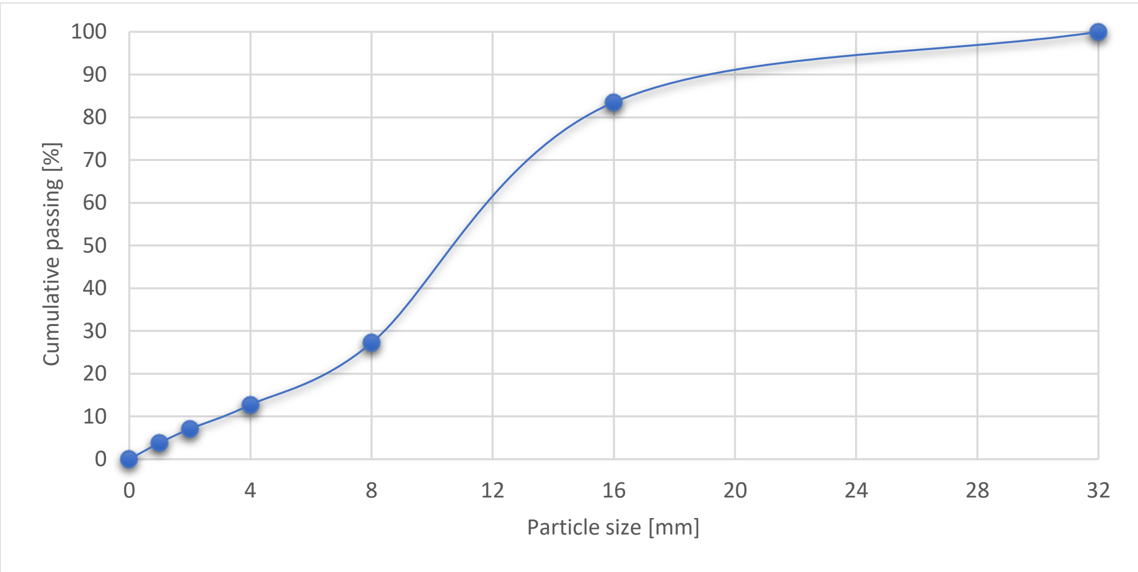
Figure 3-17 E-modulus apparatus on cylinder

The Toni 3000 is therefore stopped at 40% compressive strength and the E-modulus measuring device is removed. The compression is then continued until the compressive strength is found. The data from the Data Logger is extracted and saved in an excel file for further calculations.

4 RESULTS AND DISCUSSION

4.1 PARTICLE DISTRIBUTION CURVE

It was apparent that while a large amount of the aggregates fell within the category of 8-16mm, see figure XX, barely half a bucket of 4-8mm RCA was collected to 2.5 buckets of 8-16mm RCA. It was therefore decided to collect all RCA above 16mm and crush these on the setting 2.5. This was again sorted and helped increase the amount of available aggregates within the 4-8mm category. The setting was found through testing the options, until one was found that produced the most pieces within 4-8mm.



Graph 4-1 Particle distribution curve for the recycled concrete form the tunnel

4.2 CEMENT PASTE CONTENT

Table 4-1 Cement past content for the RCA

RCA mm	Cement paste content %
4 to 8	21.6
8 to 16	13.7

The 4-8mm RCA has nearly twice as much paste attached as the 8-16mm RCA. This is because during crushing, smaller chunks of mortar fall easily from the larger pieces, whereas the stones are harder to break into smaller pieces. This would be due to the large strength difference between mortar and stone. This will likely have a profound influence on the capacity of the concrete when later utilized.

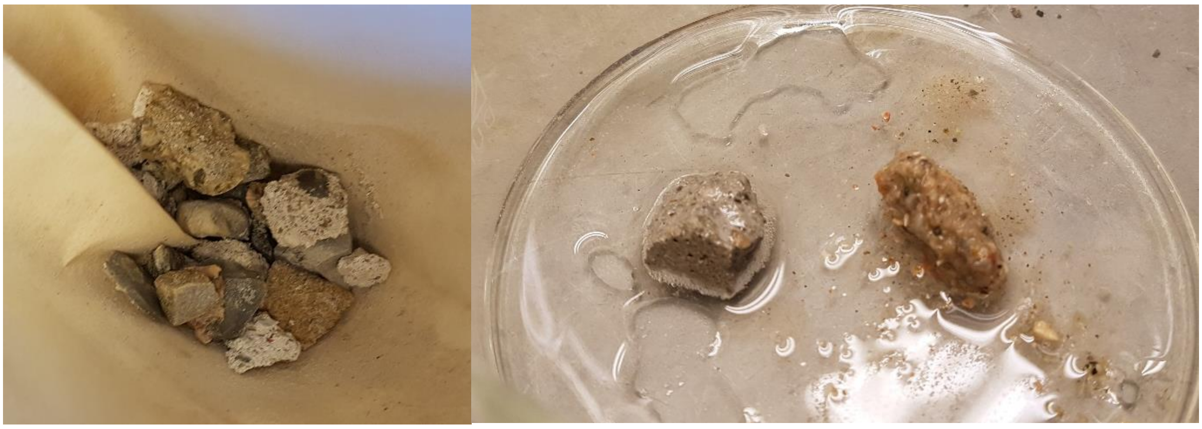


Figure 4-1 RCA after testing for cement paste content (left) and unknown substances tested with nitric acid (right)

After the test has concluded it is possible to inspect the filter bags for unknown material. It was apparent that a mortar like substance was left on some of the stones, see figure 4-1. The samples were selected and placed in a petri dish for further exposure to nitric acid. No reaction appeared, and it was thus determined not to be anything containing cement paste, as this would have reacted.

4.3 ABSORPTION

Table 4-2 Water absorption for marine sand and the RCA

Sample	Absorption %
0-4mm marine sand	0.55
4-8mm RCA	2.33
8-16mm RCA	3.87

The absorption is highest for the biggest aggregates. The absorption for the natural coarse aggregates (NA) are found to be 2.5%, using the declaration provided by NCC[4]. This is a value found using a testing method from the TI-B 75 standard, which find the critical absorption. This was chosen over the EN 1097-6 standard absorption based on the experiences gained from working in the workshop at DTU. When comparing the NA to the RCA’s absorption is it noted

[4] Send by Signe

that while the 4-8mm RCA absorption is only slightly lower than 2.5%, the 8-16mm RCA's absorption is nearly 1.5 times as high. It is possible that the low absorption in the 4-8mm RCA is because the stones absorb more than cement paste. This would also explain the high absorption of the 8-16mm RCA which mainly consists of stones. The stones found in the recycled concrete are believed to be granite and flint.

The absorption for sand found though testing indicates a higher capacity than expected, comparing to the 0.1-0.4% from NCC, though the same testing standard was used.

4.4 WATER CONTENT

Table 4-3 Water content of the RCA

Sample mm	Water content %
4 to 8	2.7
8 to 16	2.0

Table 4-4 Water content for the NA in different tests

	Sample mm	Water content %
Test 1	0 to 4	0.2
	4 to 8	0.2
	8 to 16	0.2
Test2	0 to 4	0.8
	4 to 8	0.2
	8 to 16	0.3
Test 3	0 to 4	1.5
	4 to 8	0.4
	8 to 16	0.6

The water content of the NA varied through the tests as the storage conditions were not controlled. This test was continuously done to test user friendliness of the raw state of the materials, thus not changing the state of the aggregates before adding them to the mix. The RCA was kept in closed containers, and therefore the environment remained constant only requiring one preliminary water content test.

Water content has a tremendous effect on the slump and workability of the wet concrete. If the recipe is not corrected to fit the current state of the aggregates, the w/c-ratio is affected, challenging the comparability of the results. This is an evident issue in deciphering the results.

4.5 LOS ANGELES ABRASION

Table 4-5 Los Angeles coefficient for the NA and RCA

	Sample mm	LA %
NA	4 to 8	27%
	8 to 16	35%
RCA	4 to 8	36%
	8 to 16	55%

The test was repeated twice, but showed next to no variation, see Appendix 7.2. The RCA proved to be much more perishable than the NA. This was observed during crushing and sorting, where substantial amounts of dust would appear. This could also have caused bits of the particles to decay during handling. It is notable that while it has been found that the 4-8mm RCA contains the most mortar, that 8-16mm RCA is the one with the highest LA value. This does not concur with the theory previously stated that assumes that the highest LA value is tied to the RCA with the highest cement paste content.

4.6 MIXING RECIPE

The absorption was miscalculated early in the project and the mistake was not found until after all the tests had been made. The mistake is small, and its effect on the mixes is illustrated in the table below. The correction is written in blue and indicates the difference. The difference is 59-60g in all cases and is therefore consistent enough to not affect the conclusions extrapolated from the results. The variation is so low that it is nearly insignificant. The w/c ratio is aimed to be 0.6 in all recipes, however uncertainties in densities, absorption and water content can have caused this to vary. In a few of the tests with high RCA replacement extra water has been added, as the slump was non-existent, and the uncertainties have the biggest effect.

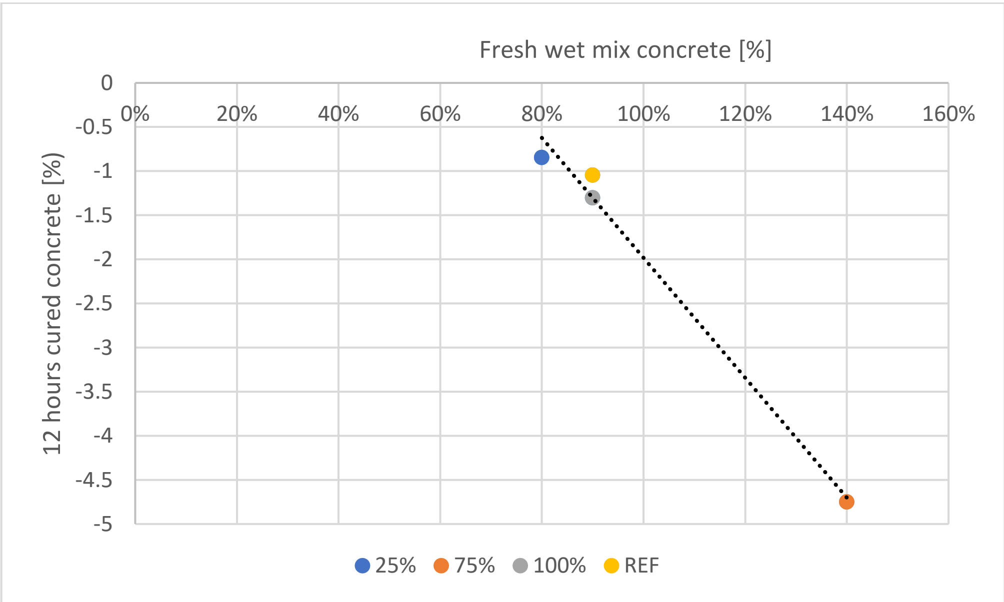
Table 4-6 Mix recipe for each testing batch, corrected for error in absorption

	Cement	Water	Sand	REF 4-8mm	REF 8-16mm	RCA 4-8mm	RCA 8-16mm
	kg	kg	kg	kg	kg	Kg	kg
REF	6.100	4.175 *+59*	17.415 *-59*	0.000	0.000	0.000	0.000
15%	6.100	3.820 *+60*	17.676 *-60*	8.145	8.153	1.452	1.387
25%	6.100	3.912 *+59*	17.554 *-59*	7.187	7.194	2.42	2.312
30%	6.100	3.653 *+60*	17.798 *-60*	0.000	0.000	0.000	0.000
50%	6.100	3.836 *+59*	17.554 *-59*	4.791	4.796	4.839	4.624
75%	6.100	3.960 *+59*	17.554 *-59*	2.396	2.398	7.259	6.936
100%	6.100	4.684 *+59*	17.554 *-59*	0.000	0.000	9.679	9.248

Note: ±XX indicates the difference between actual and calculated amounts. It is in grams.

4.7 AIR CONTENT

The air content is graphed below and appears to have the expected linear trend. The cause for negative air contents are expected, and explained in the related theory section. More data points are needed to say with certainty that the trend is linear, but the results indicate that the theory is correct. This would mean that if more tests were made these points should fall scattering along the line.



Graph 4-2 The correlation of measured and calculated air content

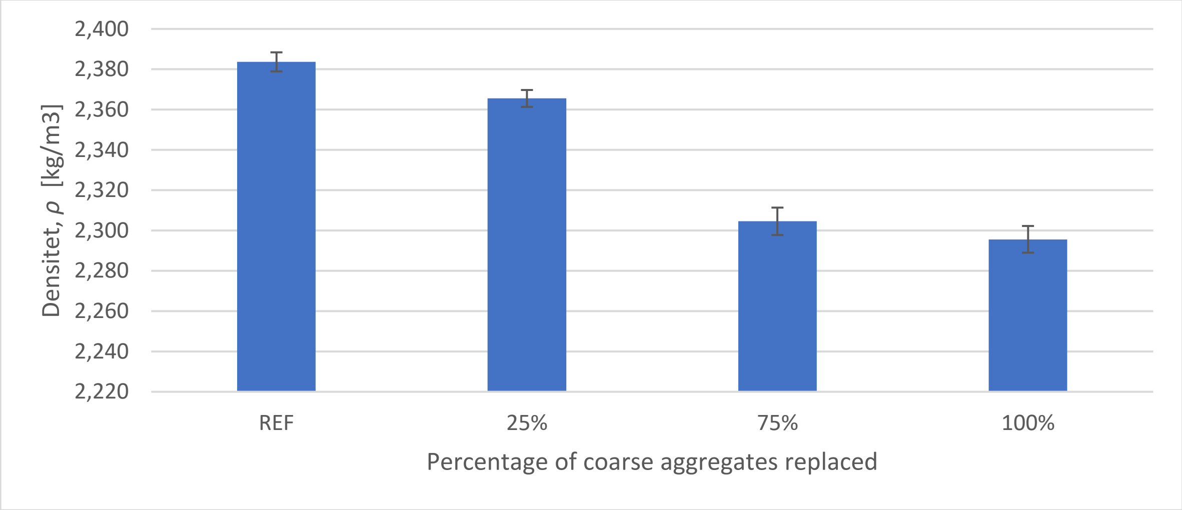
4.8 DENSITY

Table 4-7 Density of the RCA

Sample mm	Density ρ kg/m3
4 to 8	2566.9
8 to 16	2506.7

The densities of the concrete are clearly decreasing as more NA is replaced with RCA. The density of the RCA is found in table 4-7.

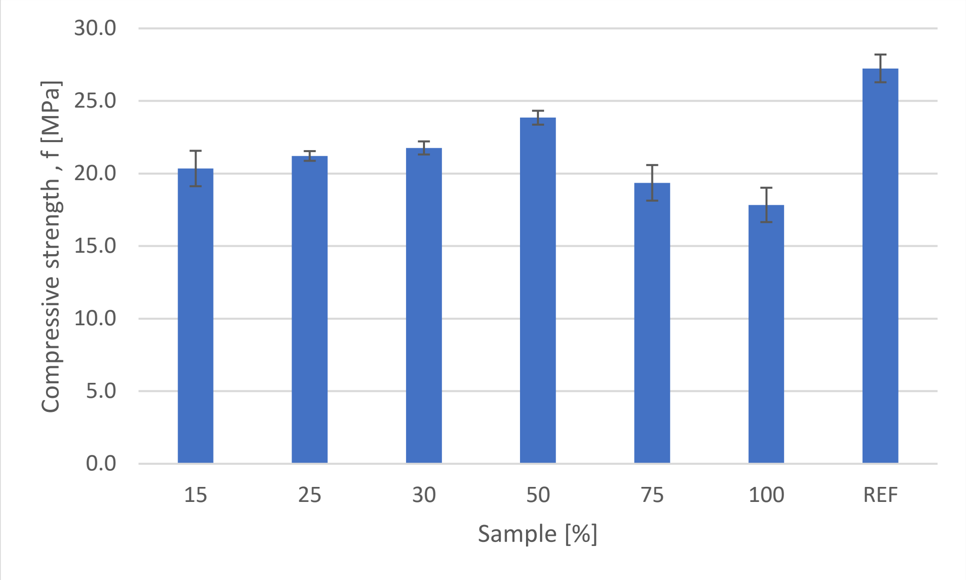
This could be because the density of the RCA is smaller than that of the marine stones, thus with the increasing replacement of RCA, the density falls. The variations of the samples are small and similar. This supports the credibility of the results.



Graph 4-3 Densities of the testing batches

4.9 COMPRESSIVE STRENGTH

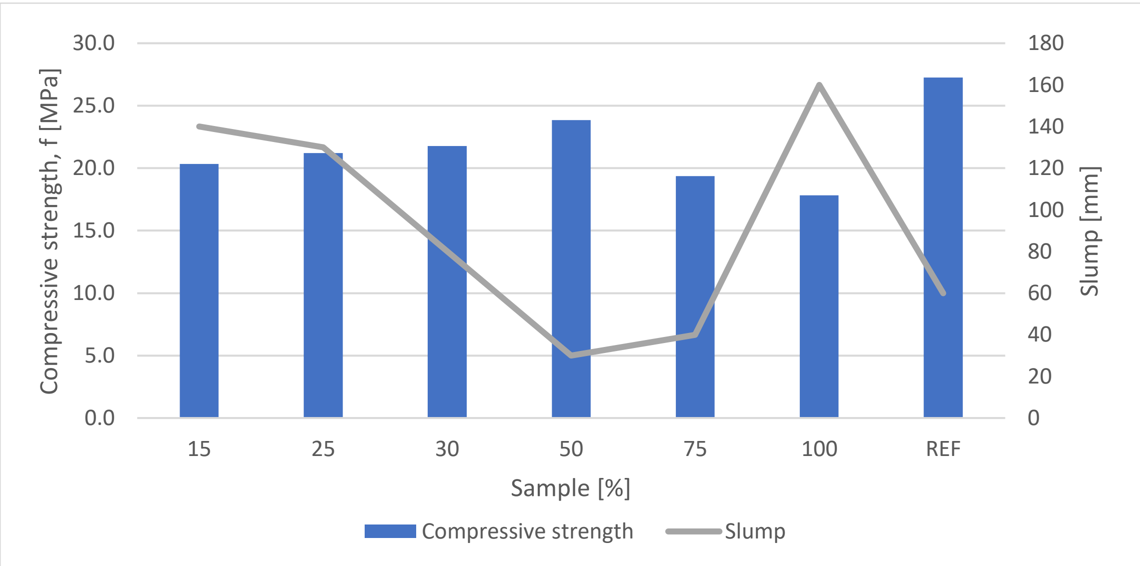
The compressive strengths of each sample are an average of four cylinders, the individual results can be found in appendix 7.6. The results on the graph below would indicate that the strength of the concrete does decrease with the use of RCA, compared to the reference test. However, the difference is minimal considering the unit is MPa. When focusing on the replacement proportions, it appears that 50% replacement with RCA is optimal for gaining the highest strength. This test also has some of the lowest deviances.



Graph 4-4 compressive strength of each sample

4.9.1 Slump

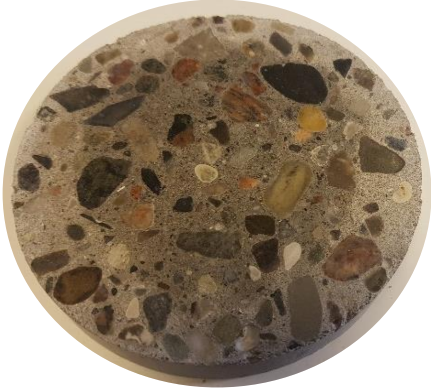
In graph 4-5, the slump decreases with the increase in RCA replacement. As stated before, extra water was added in the 75% and 100% replacement rates. This was done because the mix became dry to the extent that no slump appeared.



Graph 4-5 compressive strength and slump for each sample compared

When taking the slump of the wet concrete into account, it varies greatly over the different tests. The highest strength also has the lowest slump. A low slump has a higher chance of having too low a w/c ratio, as it is less liquid, the opposite is true for a high slump. It is not clear to say how big an effect this had on the results. However, it is worth testing further as addition information on the topic is hard to come by.

Extra cylinders were made for REF and 100% tests. These were cut into 10 slices. This was done to better get a picture of how the aggregates placed themselves inside the cylinders. The cylinders have been vibrated approximately equally. The slump of REF is 60mm and for 100% it is 160mm. Slices number 1 (top), 4 7 and 10 (bottom), are seen in figure XX.

Number	REF	100%
1		
4		
7		

10		

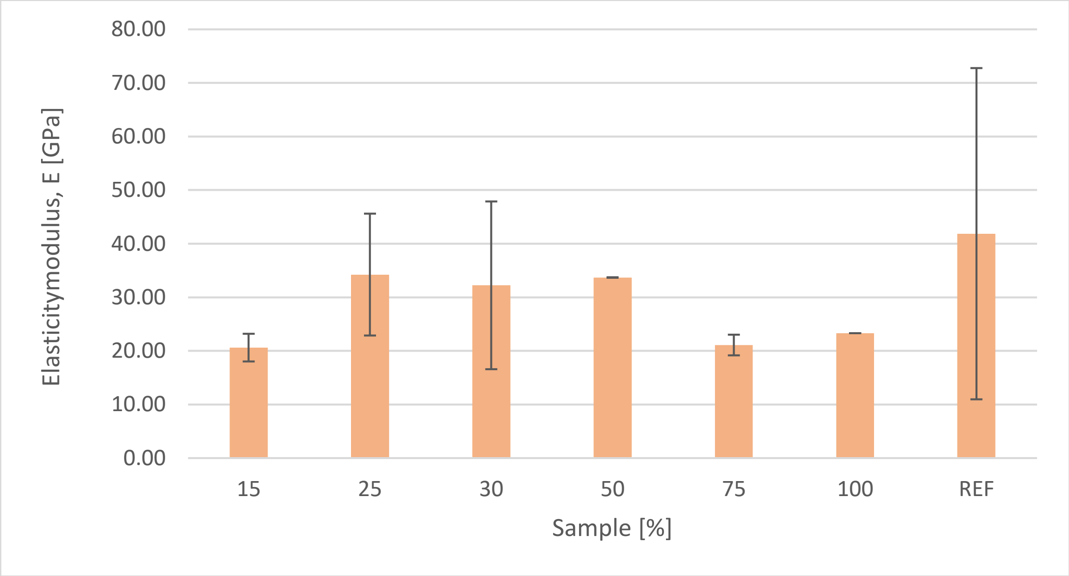
In figure XX, is it apparent that the concentration of aggregates increases with the slice number. Suggesting that they gather towards the bottom of the cylinder. This is not as apparent in the REF cylinder where the concentration stays moderately even throughout slide 4,7 and 10. Though the bigger aggregates are mainly found in slice 10.

For the 100% cylinder the aggregates containing more stones are found primarily in the bottom half of the cylinder. The lighter aggregates containing more mortar are found at the top half of the cylinder. It is also apparent that there are generally more aggregates towards the bottom half of the cylinder. This is likely due to the high slump, which indicates a wetter mix.

It can be concluded that wet mixes with a higher slump should be vibrated less to prevent as many of the aggregates to fall to the bottom, thus getting a more homogeneous cylinder composition. This may help improve the compressive strength of the cylinder, as all parts of the cylinder will equally be able to handle the force.

4.10 YOUNG'S MODULUS

Young's modulus varies not only in relation to each other, but also within one test, see appendix 7.6. This makes the data hard to read, and clearly calls for a larger number of tests to be run within one test batch, as this will help narrow down the range. According to "Bygningsingeniørens materialer" (2008) the normal possible range of concretes elasticity modulus is 10-50GPa. The test values of all the replacement tests are well within this range.



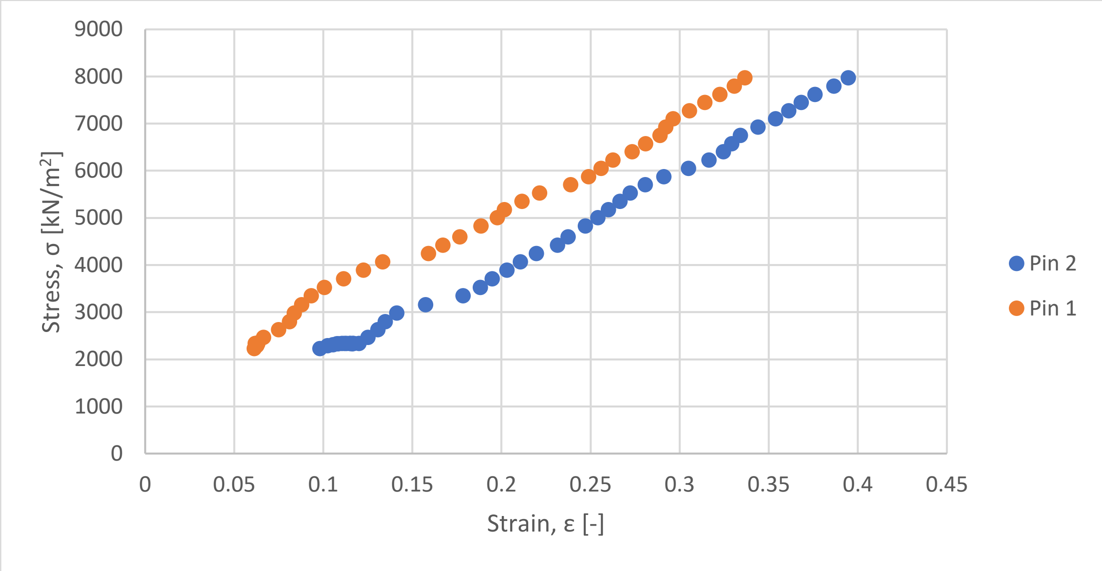
Graph 4-6 Elasticity modulus for each sample

Overall the test seems to follow the same trend as the compressive strength result, where 25%, 30% and 50% RCA replacement are more elastic. However, with the large deviances it is hard to deduce much. The E-modulus for 50% and 100% consists of only one test value as the others were of a category (c), see below.

The theoretical E-modulus of the reference test is:

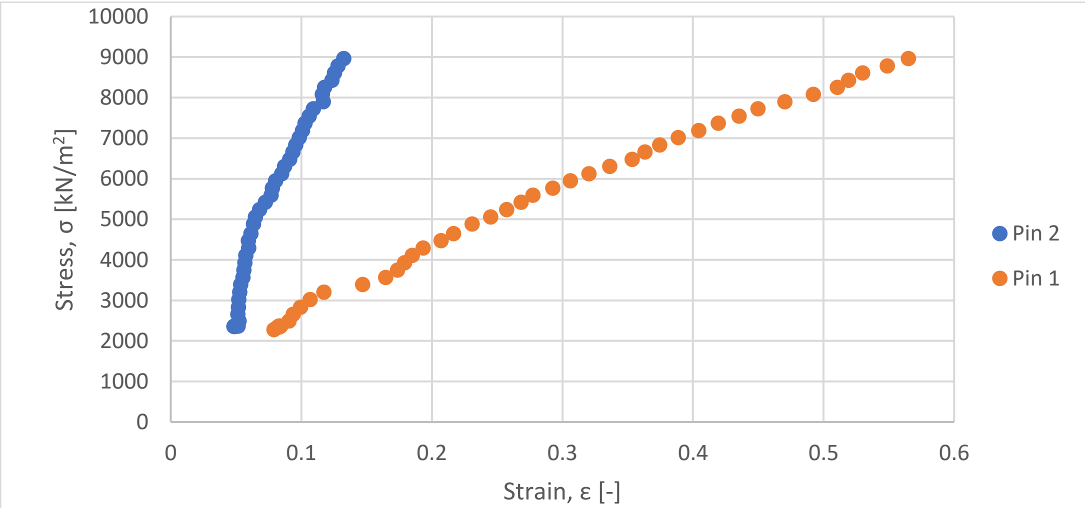
$$E_{cm} = 22 * \left(\frac{33}{10}\right)^{0,3} = 31.5 \pm 1.3GPa$$

Though this is the secant value of the E-modulus, it gives an indication of where the elasticity should be found. The test value is much higher, but has an uncertainty of ~30MPa. The tests with higher replacements of RCA has a halved E-modulus which follow accordingly to what was theoretically predicted to happen.



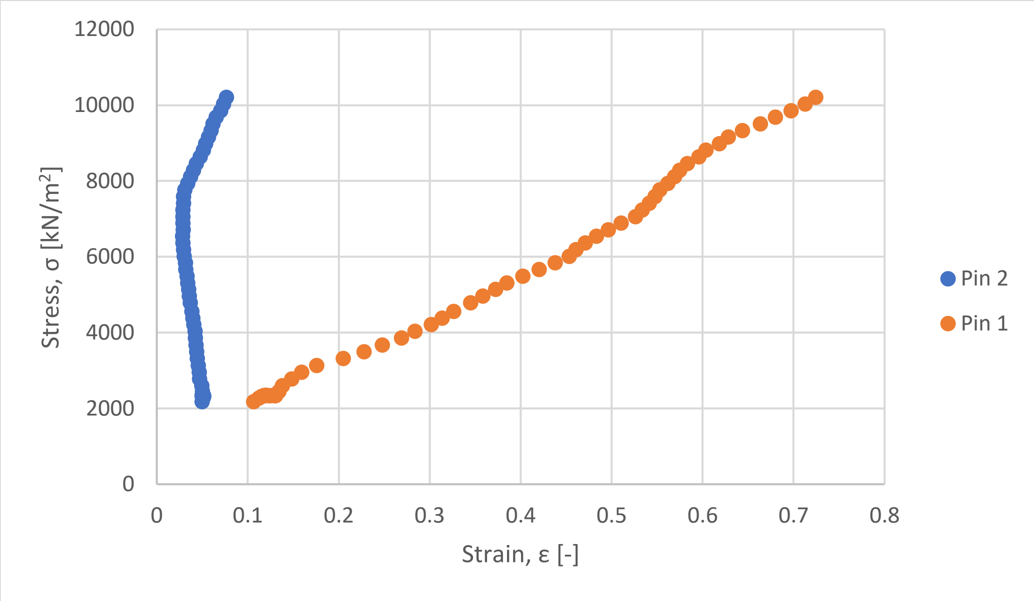
Graph 4-7 Category (a), E-modulus data from test 75% c

In graph 4-7, the two pins move homogeneously throughout the compression test.



Graph 4-8 Category (b), E-modulus data from test 25% b

In graph 4-8, the progression on both Pin 1 and Pin 2 is even. The gradient is the rate of stress per change in length, which indicates the compression head is moving as it applies pressure.

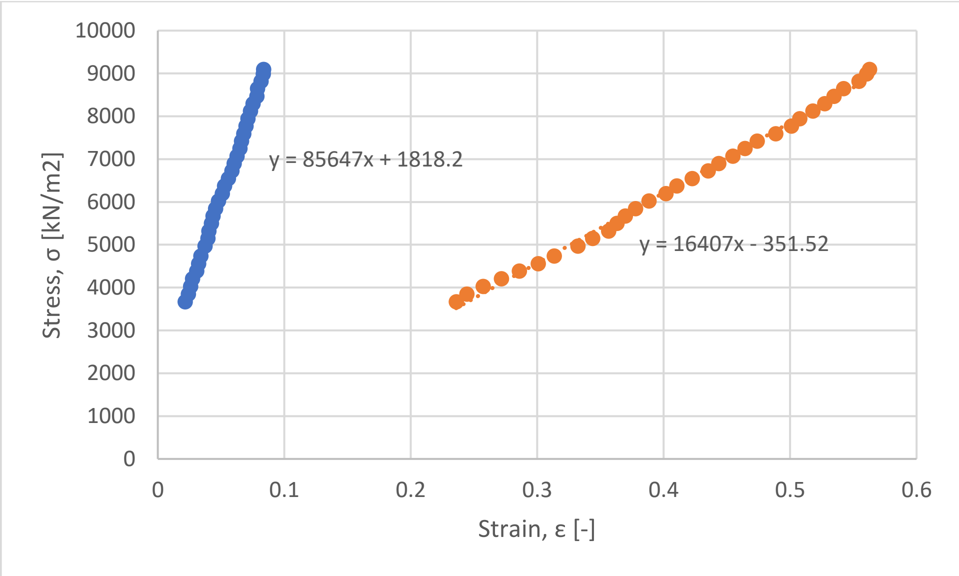


Graph 4-9 Category (c), E-modulus data from test 50% c

In graph 4-9, the progression of Pin 2 indicates that the cylinder elongates before contracting. This is the strain as it is defined as the change in length over the initial length, see theory section 2.6. Pin 1 experiences relatively even and constant compression. This indicates that the pressure surface hit the cylinder crookedly with first contact close to Pin 1, and later Pin 2.

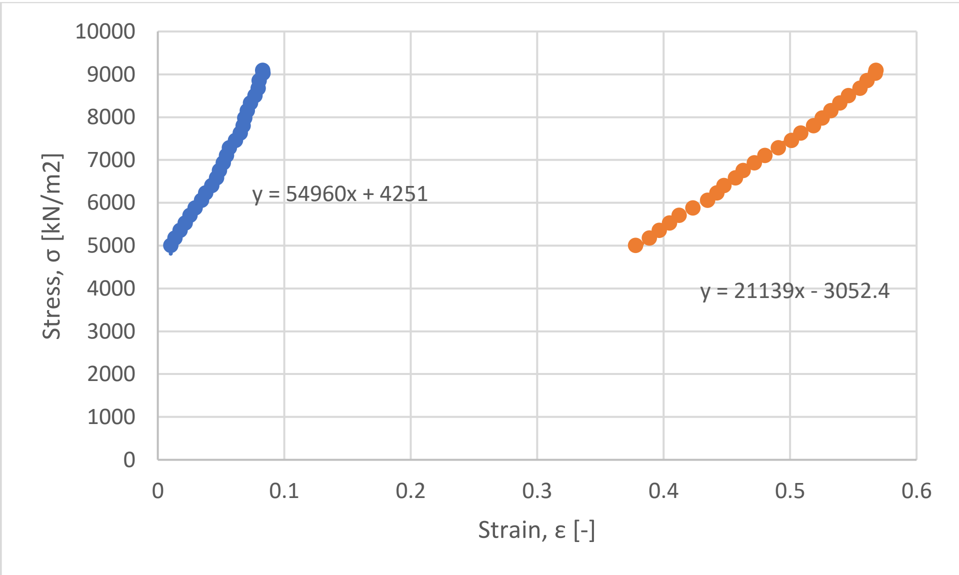
A reason for the large uncertainties is the high variations of quality of the data output from the equipment. The machine was made at DTU as an improvement to an already existing design. The improvement was adding two pins to account for uneven placement of the compression head. 3 types of measurements were identified. (a) are the most accurate and trustworthy recordings. (b) are the best example of why 2 pins are required, as to correct each other with an average value, while still being reliable. (c) are very uncertain results which cannot be used as they indicate something has gone wrong during testing. These are discarded as they are deemed untrustworthy. The many bumps in the line indicate smaller internal cracks, occurring during early compression.

The E-modulus test does not strictly follow the standard. This was done as it became apparent, though preliminary tests, that there could be a risk of early internal cracking. This is illustrated as a sharp turn in the pin curve, an example is Pin 2 in graph 4-6. Therefore, a test was done on an additional reference test cylinder to test the intended standard DS EN 1097-2, the result was 37GPa. This is close to the test results for REF of 42GPa, however looking at the earlier gradients in the test, indicates that the elasticity falls throughout the test, see graphs 4-10, 4-11 and 4-12. This suggests that all the E-modulus are likely to be a bit higher than the standardised value would be.



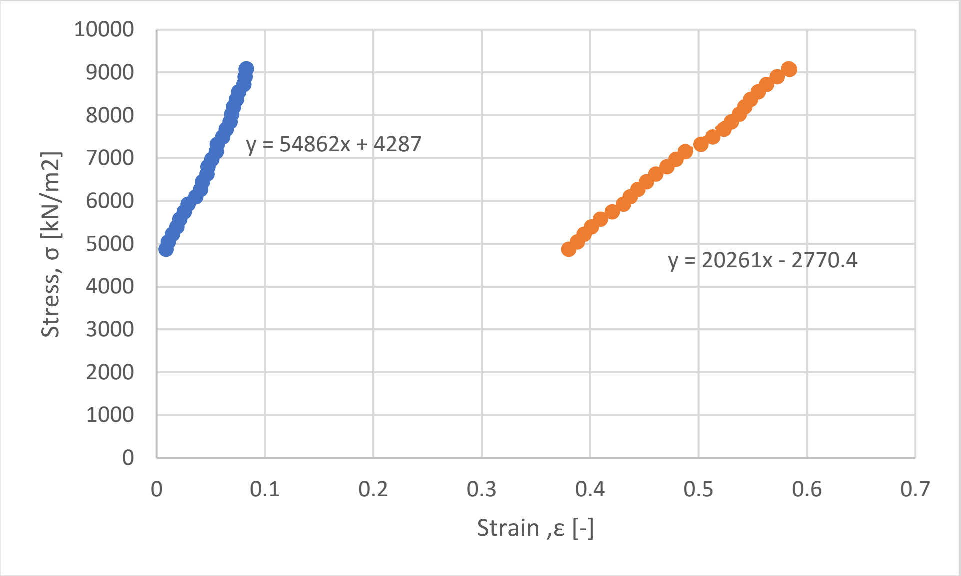
Graph 4-10 The first cycle

In graph 4-10, the E-modulus is 51.0GPa for the first cycle of the DS EN 1097-2 test.



Graph 4-11 The second cycle

In graph 4-11, the E-modulus is 38.0GPa for the second cycle of the DS EN 1097-2 test.



Graph 4-12 The third cycle

In graph 4-12, the E-modulus is 37.6GPa for the third and last cycle of the DS EN 1097-2 test.

5 CONCLUSION

With the increasing amount of RCA replacement, it can be concluded that the density will fall. The most optimal replacement level for compressive strength and elasticity is 50% RCA replacement as seen from figure 4-4 and 4-6. With a more focused investigation with aim to see how much the slump affects the strength and elasticity a more precise answer can be found. It is found through the Standard method from DS EN 1097-2 that the E-modulus decreases after repeated tests, and the true accepted values is found after 3 repetitions.

It is concluded that though 4-8mm RCA has more cement paste content than 8-16mm RCA, the later has a higher water absorption and LA value. The LA values for the RCA is higher than for the NA, as expected.

When considering the state of the materials, it is concluded that a big amount of characterising data is required to utilize the aggregates from raw states. However, a better technique for determining the absorption of RCA is required to avoid lacking water in the mix at high RCA replacement rates.

6 FUTURE WORK

It is of interest to investigate loss of cement in the aggregates occurring during the crushing, as the material tended to crumble easily, thus losing a lot of cement to a powder like state. A possibility was to use this in aiding with investigations concerning the replacement of the sand with RCA in concrete.

Due to the high spread in E-modulus results, more tests regarding the E-modulus with focus on getting a larger quantity of the test samples for each replacement percentage tested, will give more accurate E-modulus results. Using different apparatus to test the E-modulus may give more consistent readings.

The slump varies a lot in this test, and testing the influence of the slump on a reference sample, will give a better understanding of its influence on the results.

A better technique for determining absorption is called for, and this would be a highly sought-after aspect to improve. As it would allow for a much more precise mix recipe.

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7.1 STANDARDER

DS/EN 1097-2

Tests for mechanical and physical properties of aggregates –
Part 2: Methods for the determination of resistance to fragmentation

DS/EN 12602+A1

Aggregates for concrete

8 APPENDICES

8.1 CEMENT PASTE CONTENT

	Sample	Dry mass	Filter	Dish	Tested sample	Cement paste mass	Cement paste content
	mm	g	g	g	g	g	%
a	8 to 16	50.00	6.45	105.17	41.17	8.83	17.66
b		50.06	6.49	106.19	44.14	5.92	11.83
c		50.08	6.72	105.07	44.31	5.77	11.52
Average						6.84	
							13.67
a	4 to 8	20.04	6.88	104.80	14.84	5.20	25.95
b		20.06	6.50	104.70	15.95	4.11	20.49
c		20.07	6.75	107.77	16.36	3.71	18.49
Average						4.340	
							21.64

8.2 LA COEFFICIENT

	Sample mm	Sample mass g	Retained mass g	Procent remaining %	LA %
Test 1	NA				
	4 to 8	1500	1097.23	73%	27%
	8 to 16	1500	961.53	64%	36%
	RCA				
	4 to 8	1500	952.95	64%	36%
	8 to 16	1500	659.32	44%	56%
Test 2	NA				
	4 to 8	1500	1081.75	72%	28%
	8 to 16	1500	976.50	65%	35%
	RCA				
	4 to 8	1500	973.66	65%	35%
	8 to 16	1500	686.81	46%	54%

8.3 DISTRIBUTION CURVE

Intervals	mass of sieves	Retained mass	Fall though	Percentage
mm	kg	kg	g	%
32	1.440	0.000	9.975	100.0
16	1.295	1.645	8.330	83.5
8	1.180	5.615	2.715	27.2
4	0.980	1.445	1.270	12.7
2	0.985	0.565	0.705	7.1
1	0.880	0.325	0.380	3.8
0	0.765	0.380	0.000	0.0

Total mass after sieving	9.975
Initial mass	10
Sieving rest	0.025

8.4 WATER OCNTENT

RCA

	Sample	Tray	Wet mass	Dry mass	Water content	Water content	Average
	mm	g	g	g	g	%	%
a	4 to 8	35	200	195	5	2.5	2.7
b		35	200	194	6	3.0	
c		35	200	195	5	2.5	
a	8 to 16	35	200	196	4	2.0	2.0
b		217	200	196	4	2.0	
c		215	200	196	4	2.0	

NA first test done

	Sample	Tray	Wet mass	Dry mass	Water content	Water content	Average
	mm	g	g	g	g	%	%
a	0 to 4	35	200	200	0	0.0	0.2
b		35	200	200	0	0.0	
c		36	200	199	1	0.5	
a	4 to 8	35	200	200	0	0.0	0.2
b		35	200	200	0	0.0	
c		36	200	199	1	0.5	
a	8 to 16	35	200	200	0	0.0	0.2
b		35	200	200	0	0.0	
c		35	200	199	1	0.5	

NA second test done

	Sample	Tray	Wet mass	Dry mass	Water content	Water content	Average
	mm	g	g	g	g	%	%
a	0 to 4	36	200	198	2	1.0	0.8
b		35	200	198	2	1.0	
c		35	200	199	1	0.5	
a	4 to 8	35	200	200	0	0.0	0.2
b		35	200	200	0	0.0	
c		36	200	199	1	0.5	
a	8 to 16	267	200	199	1	0.5	0.3
b		217	200	199	1	0.5	
c		214	200	200	0	0.0	

NA third test done

	Sample	Tray	Wet mass	Dry mass	Water content	Water content	Average
	mm	g	g	g	g	%	%
a	0 to 4	36	300	296	4	1.33	1.4
b		36	300	296	4	1.33	
c		36	300	295	5	1.67	
a	4 to 8	36	300	299	1	0.33	0.4
b		36	300	299	1	0.33	
c		36	300	298	2	0.67	
a	8 to 16	36	300	299	1	0.33	0.6
b		36	300	298	2	0.67	
c		36	300	298	2	0.67	

8.5 ABSORPTION

0-4mm is the marine sand.

4-8mm and 8-16mm is RCA.

	Sample	Tray	s.s.d.-state	Dry	Absorption	Average
	mm	g	g	g	%	%
a	0 to 4	214.37	200.07	199.61	0.23	0.54
b		216.63	200.15	197.68	1.23	
c		214.72	200.01	199.68	0.16	
a	4 to 8		153.3	150	2.15	2.28
b			153.4	150	2.22	
c			153.8	150	2.47	
a	8 to 16		156.3	150	4.03	3.72
b						
c			155.3	150	3.41	

8.6 RAW TEST DATA

Sample	Diameter	Height	Weight	Slump	Air content	Compresisve strength - 7 days		E-modul	Volume of cylinder	Volume of constituents
	mm	mm	kg	mm	%	kN	Mpa	Gpa	m3	m3
50%	99.7	200	3.609	30	1.6	191	24.5		0.00156	0.00154
	100	199	3.598			174	22.2	33.693	0.00156	0.00154
	100	200	3.611			196	25.0	15.553	0.00157	0.00155
	100	200	3.622			187	23.8	56.24615	0.00157	0.00155
15%	99.3	199	3.612	140	1.3	158	20.4		0.00154	0.00154
	100	200.3	3.609			156	19.9	20.4765	0.00157	0.00154
	99.7	199.7	3.615			160	20.5	23.263	0.00156	0.00154
	99.7	200	3.621			161	20.6	18.106	0.00156	0.00154
100%	100	199.7	3.554	160	0.9	143	18.2	197.7255	0.00157	0.00209
	99.8	200	3.563			138	17.6		0.00156	0.00210
	99.7	199	3.538			135	17.3	39.182	0.00155	0.00209
	100	199.7	3.57			143	18.2	23.31	0.00157	0.00210
25%	99.2	199.2	3.645	130	0.80	166	21.5		0.00154	0.00156
	99.3	199	3.661			162	20.9	47.2955	0.00154	0.00157
	99.5	199.8	3.669			161	20.7	28.951	0.00155	0.00157
	99.2	200	3.665			168	21.7	26.4855	0.00155	0.00157
75%	99.8	198.2	3.578	40	1.40	140	17.9		0.00155	0.00165
	99.8	199	3.583			147	18.8	22.463	0.00156	0.00165
	100	199.8	3.579			160	20.4	19.7375	0.00157	0.00165
	100	199.2	3.585			160	20.4	30.5065	0.00156	0.00165
30%	100	200	3.628	80	1.7	171	21.8		0.00157	
	100	200.6	3.612			161	20.5	27.8445	0.00158	
	99.36	200	3.616			181	23.3	49.609	0.00155	
	99.6	200	3.629			167	21.4	19.2465	0.00156	
REF	100	199.3	3.688	60	0.9	209	26.6		0.00157	0.00157
	100	200	3.709			212	27.0	19.9005	0.00157	0.00158
	100	199.2	3.694			226	28.8	77.2055	0.00156	0.00157
	99.8	199.5	3.701			215	27.5	28.5055	0.00156	0.00157
	100	199.5	3.709			207	26.4	37.5615	0.00157	0.00158
	100	199.3	3.679						0.00157	0.00156

8.7 AIR CONTENT AND DENSITY TEST DATA

	24 hours		7 days	
	Mass in air	Mass in water	Mass in air	Mass in water
25%	kg	kg	kg	kg
A	3.626	2.084	3.645	2.107
B	3.644	2.099	3.661	2.115
C	3.651	2.100	3.669	2.115
D	3.647	2.098	3.665	2.114
75%				
A	3.552	2.008	3.578	2.032
B	3.557	2.002	3.583	2.027
C	3.552	1.997	3.579	2.022
D	3.559	2.004	3.585	2.028
100%				
A	3.539	1.99	3.554	2.003
B	3.545	1.995	3.563	2.011
C	3.515	1.972	3.538	1.991
D	3.551	2.001	3.57	2.02
E	3.531	1.988	3.55	2.007
REF				
A	3.668	2.12	3.688	2.139
B	3.688	2.138	3.709	2.155
C	3.671	2.121	3.694	2.143
D	3.681	2.133	3.701	2.152
E	3.689	2.137	3.709	2.155
F	3.659	2.112	3.679	2.131

8.8 MIXING RECIPE DATA

Theoretical composition of 1m^3 concrete
components are assumed to be in ssd-state

v/c	0.6		
Sand percentage	0.47	%	
Components	Density [kg/m^3]	Mass [kg]	Volume [m3]
Cement	3100	305	0.098
water	1000	183	0.183
Air	2620		0.01
R			0.291
T			0.709
Marine sand	2620	873	0.333
Marine stone (4-8)	2610	417	0.160
Marine stone (8-16)	2610	417	0.160
4-8 RCA	2566.9	72.3	0.0282
8-16 RCA	2506.7	70.6	0.0282

The orange marked values will vary with the RCA replacement percentage.

Correction with respect to water content and absorption.

For a 20L mix, without the corrected absorption.

15%

	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	1.5	0.2	0.3	2.74	2.04
C=(A-B)	-1.29	2.3	2.2	-0.41	1.83
G	17.452	8.33	8.33	1.4	1.4
Content of aggregates corrected for moist	17.676	8.145	8.153	1.452	1.387
Correcting water amount	-0.225	0.187	0.179	-0.006	0.025
Total amount of water to add	0.160				

25%

	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	0.8	0.2	0.3	2.74	2.04
C=(A-B)	-0.59	2.3	2.2	-0.41	1.83
G	17.452	7.35	7.35	2.4	2.4
Content of aggregates corrected for moist	17.554	7.187	7.194	2.420	2.312
Correcting water amount	-0.103	0.165	0.158	-0.010	0.041
total amount of water to add	0.252				

30%

	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	2.2	0.2	0.3	2.74	2.04
C=(A-B)	-1.99	2.3	2.2	-0.41	1.83
G	17.452	6.86	6.86	2.9	2.8
Content of aggregates corrected for moist	17.798	6.708	6.714	2.904	2.775
Correcting water amount	-0.347	0.154	0.147	-0.012	0.050
Total amount of water to add	-0.007				

50%

	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	0.8	0.2	0.3	2.74	2.04
C=(A-B)	-0.59	2.3	2.2	-0.41	1.83
G	17.452	4.90	4.90	4.8	4.7
Content of aggregates corrected for moist	17.554	4.791	4.796	4.839	4.624
Correcting water amount	-0.103	0.110	0.105	-0.019	0.083
Total amount of water to add	0.176				

75%

	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	0.8	0.2	0.3	2.74	2.04
C=(A-B)	-0.59	2.3	2.2	-0.41	1.83
G	17.452	2.45	2.45	7.2	7.1
Content of aggregates corrected for moist	17.554	2.396	2.398	7.259	6.936
Correcting water amount	-0.103	0.055	0.053	-0.029	0.124
Total amount of water to add	0.100				

100%

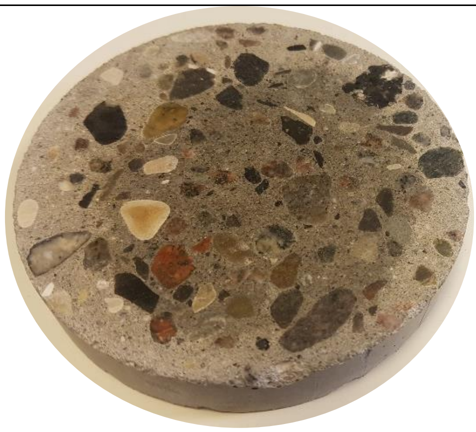
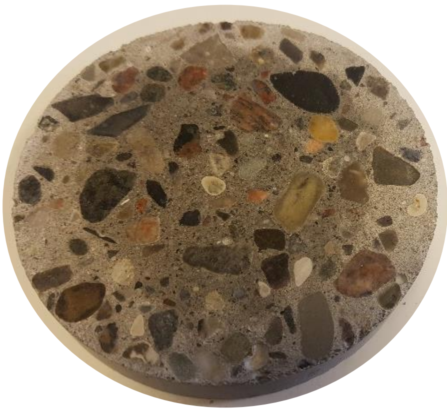
	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	0.8	0.2	0.3	2.74	2.04
C=(A-B)	-0.59	2.3	2.2	-0.41	1.83
G	17.452	0.00	0.00	9.6	9.4
Content of aggregates corrected for moist	17.554	0.000	0.000	9.679	9.248
Correcting water amount	-0.103	0.000	0.000	-0.039	0.166
Total amount of water to add	0.024				

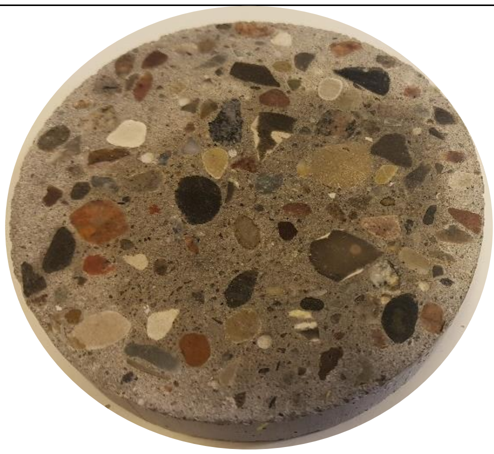
REF

	Marine sand 0-4	Marine stone 4-8 mm	Marine stone 8-16 mm	RCA 4-8	RCA 8-16
water absorption [%] A	0.21	2.5	2.5	2.33	3.87
Water content [%] B	0.00	0.00	0.00	2.74	2.04
C=(A-B)	0.21	2.50	2.50	-0.41	1.83
G	17.452	9.80	9.80	0.0	0.0
Content of aggregates corrected for moist	17.415	9.563	9.563	0.000	0.000
Correcting water amount	0.037	0.239	0.239	0.000	0.000
Total amount of water to add	0.515				

8.9 CYLINDER SLICES

Number	REF	100%
1 (top)		
2		
3		

4		
5		
6		
7		

8		
9		
10 (bottom)		

The white stones in the Ref sample appear to be limestone and was observed to crack easily during testing.

8.10 CEMENT PASTE CONTENT

Syreoplukning af beton

A **Princip**

Betonprøven knuses og cementpastaen opløses i salpetersyre. Alle chlorider vil Herefter være opløst. Uopløselige dele filtreres fra, og mængden af chlorid i væskefasen bestemmes ved titrering med sølvnitrat.

Metoden bestemmer ikke på hvilken form chloriden findes i betonprøven. Den siger ikke, om chloriden findes som natriumchlorid (almindelig salt), calciumchlorid eller andre chlorider.

B **Specielt apparatur**

Titrator 716 DMS Titrino

C **Kemikalie sikkerhed**

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

Læs kemikaliebrugsanvisningen før arbejdet begynder.

D **Reagenser**

1) **Salpetersyre 1% HNO_3:**
17 mL koncentreret HNO_3 overføres med måleglas til en 1000,00 mL målekolbe som er ½ fyldt med destilleret vand. Der blandes godt og tilsættes vand til mærket. Efter blanding overføres opløsningen til en plastikflaske og mærkes.

E **Analysens udførelse**

5 g tørret knust prøve afvejes på teknisk vægt til en konisk kolbe. Der tilsættes ca. 50 mL varmt destilleret vand og det blandes.

Derefter tilsættes der langsomt 10 mL konc. HNO_3 til opslemningen som derefter blandes godt og stilles til afkøling til stuetemperatur (skal foregå i stinkskab).

Der tilsættes ca. 1mL konc. HNO_3 for at kontrollerer at alt materiale er opløst (luftudvikling). Fortsæt med at tilsætte HNO_3 indtil der ikke er mere luftudvikling.

Filtrer opløsningen gennem alm filter ned i et bægerglas. Skyl filtreret med 1% HNO_3 Tilsæt destilleret vand til ca. 150 mL volumen.

Titrer prøven – se vejledning for chlorid titrering

F **Affaldshåndtering**

Ekstrakerne hældes i affaldsdunk mærket X 4.41 (tungmetaller).

Filterpapiret bortkastes i skraldespanden i stinkskabet.