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Recycling of cement and aggregates from demolition concrete

—A study of the effect on separation by thermal decomposition of concrete

Bachelor Thesis Chemical Engineering

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Abstract

With the increasing amount of construction and demolition waste (C&DW), environmental problems and their effects on humans are becoming more extensive. Therefore, it is necessary to find suitable solutions to avoid or at least minimize these problems. Concrete consists of several materials, which have different physical and chemical properties, and that means that more than one method or process could be used to obtain the desired results. In this study, the recycled concrete is divided into two parts, thermal and non-thermal treated, to study the thermal effect. Both parts are exposed to mechanical processes such as crushing and sieving, to obtain required fractions. The aggregates, the largest mass of the concrete, could be separated from the cement by the mechanical processes into several fractions according to the required size. The fine fractions are almost pure cement and here the challenge is how to reuse the cement, especially after losing its original properties. X-Ray diffraction (XRD) and optical microscope were used to analyze the fractions. The fine fractions, which are almost pure cement, show that they could be used again when mixed with newly produced cement without losing much of its original strength. Results shows that the final strength, after 28 days, on a concrete mixture with 25 % fine fraction (<0.075-0.125 mm) and 75 % new cement is 44.6 N/mm² compared with 53.3 N/mm² final strength on the concrete mixture with 100 % new cement.

Acknowledgements

We would like to thank Ida Gabrielsson at Rise (Research Institutes of Sweden) for all the help with the mechanical and physical tests and NCC recycling for providing the demolished concrete.

We would like to express our gratitude to our examiner Ulf Jäglid and our supervisor Rikard Ylmén for their support and guidance and to Ulrika Johansson for the help with proofreading the report.

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1. Introduction

1.1 Waste and environmental impact

The growing population of about 7 billion people leads to an increase in construction and demolition (C&D) activities, giving large amount of waste around the world. This is one of the main reasons of concern when producing large quantities of building materials, especially cement [1].

The waste generated by construction and demolition processes is one of the largest waste fractions in the world and it consists of several main parts: concrete, metal, wood, plastics and other mixed fractions. The materials used in the construction of buildings change their properties during aging. This means that the construction and the demolition will continue, old buildings will be demolished and new ones will be constructed, and with this, waste will be produced. With an increase of waste, due to increased building and demolition, there will be new challenges to face and there is a need to find solutions for these new challenges. The waste generated by C&D in Europe is one billion tons every year, and that is one third of the total waste generated in Europe. The C&DW (construction and demolition waste) generated in the USA is 123 million tons per year [2, 3].

The production and usage of concrete have different environmental impacts and the two main factors are energy consumption and carbon dioxide emissions from the production. In the manufacturing of cement there is a large need of energy due to the process requiring temperatures up to 1500 °C. Also during the manufacturing of cement, a large amount of calcium carbonate needs to be calcined and during this reaction, as a byproduct, large amounts of carbon dioxide are produced. In this process, for every ton of cement produced, 0.8 tons of carbon dioxide is created. In addition to these two factors, there are other things that contribute to the environmental impact, such as emissions from transports and mining in the quarries [4, 5 and 6].

1.2 Earlier work on concrete recycling

The environmental impact caused by the manufacturing of new cement and its negative effect on human health, such as dust and ash, has led to an increased interest in the reuse of C&DW (concrete and demolition waste). Previous studies and tests that have been done on the reuse of demolition concrete were mainly focused on the recovery of aggregates, such as stone, gravel and sand, from the concrete using a crushing process [3]. The previous studies also focused on the energy consumption of the recovery process and what could be done to make it more energy efficient [2].

In the process of recovering the aggregates from the demolished concrete, the reinforcement bars are first separated from the concrete and later the concrete is crushed to desired size. The crushed concrete can then be used as recycled concrete aggregates (RCA) in the mixing of new concrete. The problem with using RCA in new concrete is that they have higher water

absorption than fresh aggregates. This is due to that most of the cement paste still is attached to the aggregates [3].

In an earlier study, an attempt to separate more of the cement paste from the aggregates to improve the quality of the aggregates was made. The concrete was first thermally treated to make the separation of cement from the aggregates easier. The results show that after the thermal treatment less of the cement paste is still attached to the aggregates [7]. Again, the focus was only on the recovery of aggregates and not on the cement.

As for the recovery of the cement paste from concrete, and the reuse of cement, there has been little or no research in this field of C&DW research. No information or reference material could be found about the recovery of cement and its usages. So in this study, the main focus was on the recovery of the cement paste from concrete and the reuse of the cement.

1.3 Concrete

Concrete is a mixture of different materials such as cement, water, aggregates (stones, sand and gravel) and other filler materials. To mix a concrete with good properties it is important that the mixing materials have good physical and chemical properties, such as texture, weight, moisture content, permeability, water absorption, density and size of aggregates. These properties need to be taken into account when mixing the concrete, so it can withstand the specific environmental conditions at the place of construction [2].

Today, a commonly used cement in concrete is the Portland cement. Portland cement was first produced by the British construction worker Joseph Aspdin in 1824 and Portland cement is what is called a hydraulic cement. A hydraulic cement is a cement that cures under wet conditions in contrast to a non-hydraulic cement that use the carbon dioxide in the air to cure [8]. The Portland cement consists of the compounds di- and tri-calcium silicate (Ca_2SiO_4 and Ca_3SiO_5) as the main components. It also contains lower amounts of calcium aluminate ($\text{Ca}_3\text{Al}_2\text{O}_6$) and calcium aluminoferrite ($\text{Ca}_2(\text{Al,Fe})_2\text{O}_5$). The manufacturing of the cement is done by grinding limestone with other minerals and burn it at $1450\text{ }^\circ\text{C}$ to produce the clinker. During the grinding gypsum is also added as an additive to control the setting time of the calcium aluminate in the cement. Without the gypsum the cement will immediately cure when mixed with water [9].

When cement, aggregates and water are mixed together, concrete will be formed. The water will react with the cement and activate the hydration process. The water reacts with the two calcium silicates (Ca_2SiO_4 and Ca_3SiO_5) and forms two new compounds: Calcium hydroxide and calcium silicate hydrate. These two compounds will harden and bind the aggregates together and give the concrete its strength. During the mixing process, air is introduced into the concrete. In fact there are two types of air: desired air and undesired air. The undesired air consists of large air bubbles in the concrete and causes loss of strength. On the other hand, the desired air consists of microscopic air bubbles that will not cause strength loss but instead make the concrete lighter and more durable [8, 10].

2. Aim

The aim of this study was to examine if it is possible to separate the cement and the aggregates from demolition concrete by using thermal treatment before the separation. Another aim was to determine the characteristics of the recycled materials and to examine the possibility to reuse the cement as filler material in new concrete.

3. Theory

3.1 X-ray Diffraction

X-ray diffraction (XRD) is a technique used to identify crystalline materials. It works by emitting a monochrome X-ray beam at the sample and measures the scatter of the reflecting beams at different angles. XRD is easy to use and gives precise results in times varying between minutes to hours. Furthermore, it also gives information about phases and structures and this makes it widely used in many fields, such as biology, chemistry, pharmaceuticals and geology. The method used in this paper is to characterize cement materials in a non-destructible way, as well as to quantify the different phases within the materials [11, 10]. With an XRD, two different analysis can be made, qualitative and quantitative analysis. With help of a large database, in the XRD-software, with a vast amount of data on different compounds the qualitative analysis can be made. With that, the peak height and bottom area of the peaks are proportionate to the concentration of the sample and the information from the test can be used to make a quantitative analysis of the sample.

4. Experimental

4.1 Materials

The concrete (Image 1) used in this study was collected at a NCC Recycling facility and came from a demolition site in the Johanneberg region in Gothenburg, Sweden. The buildings, mostly residential, in this area were built between the 1930s and 1950s.



Image 1. The concrete that was used in the study. The reinforcing bars had been removed before the concrete was received.

Image 2 and 3 show some of the tools that were used in the study. The rubber sledge (Image 2) that was used is an ordinary hand-held sledge that can be purchased in a hardware store. In Image 2, the metallic containers that were used to mill the crushed concrete are also shown. The containers were used together with a ball mill (Envisense RJM-103) shown in Image 3.



Image 2. The hand-held rubber sledge and metallic containers that were used in the study. The rubber sledge is an ordinary hand-held sledge from a hardware store.



Image 3. The ball mill that, together with the metallic containers (Image 2), was used to mill the concrete.

4.2 Heating and weighing of the concrete

Five samples of untreated concrete, approximately 1 kg each, were weighed and then left to dry in a furnace at 120 °C for three days. After three days the samples were weighed again. Samples 1 to 3 were then heated to 400 °C. They were left in the oven for 17 hours and then taken out and weighed. Sample one was heated once more to 400 °C. The same procedure with the second and third sample were done at a temperature of 650 °C and here the second sample was heated twice with weighing between the first and second time. In the last step the third sample was heated to 1000 °C twice.

4.3 Crushing and separation of cement and aggregates

In this section, the method that was used to separate the cement and aggregates from each other in the demolition concrete is explained.

4.3.1 Thermal treated concrete

The method was developed by doing a small test batch by using roughly 900 g of untreated concrete. It was heated to 650 °C in a furnace for approximately 17 hours and then left to cool to a workable temperature. The crushing of the samples was done by hand with a rubber sledge (Image 2). The samples were crushed to pieces roughly the size of the biggest aggregates. As little force as necessary was used to crush the concrete to leave the aggregates as intact as possible. The first separation was made into two fractions by sieving it, one was bigger than 4 mm and the other one was smaller than 4 mm. The two fractions were milled in batches on a steel ball mill for one hour and were then sieved into the final fractions which are <0.075 mm, 0.075-0.25 mm, 0.125-0.25 mm, 0.25-0.5 mm, 0.5-1 mm, 1-2 mm, 2-4 mm, 4-8 mm and into 8 mm and bigger. The <0.075 and 0.075-0.125 mm fractions are called the cement fractions (fine fractions) in this report and the others are called sand and gravel fractions (aggregates). The batch was analyzed with X-ray diffraction (see separate section below) and optical microscope (Nikon SMZ800) to observe if a good separation was obtained and if some optimizing was needed. Based on the results from the test batch the following procedure was used to separate the aggregates and cement in the concrete:

1. Crush the concrete to smaller bits of roughly 1 kg.
2. Heat the samples to 650 °C.
3. Crush the samples with a rubber sledge to smaller pieces, roughly the same size as the largest aggregates.
4. Sieve into two fractions. One larger than 4 mm and one smaller than 4 mm.
5. Mill the two fractions in a ball mill with steel balls for one hour.
6. Separate again into the final fractions, <0.075, 0.075-0.125, 0.125-0.25, 0.25-0.5, 0.5-1, 1-2, 2-4, 4-8 and >8 mm.
7. The fraction 2-4 mm might need to be milled once more. This was decided based on an ocular inspection of the fraction.

Roughly 11kg of concrete were used to make the bulk material. The bulk material was used in different mixes to be casted into prisms and then tested for durability and a reference mixture was also used and slump flow tests were made.

4.3.2 Non-thermal treated concrete

A small batch was produced by following the procedure described in the above section, except that the thermal treating step (step 2) was excluded. Also, a steel hammer was used to crush the concrete in step 3, as the concrete was too hard for the rubber sledge. The untreated batch was also analyzed with X-ray diffraction and optical microscope.

4.4 X-Ray diffraction

In the following section the two different XRD analysis and their parameters are presented.

4.4.1 Qualitative analysis

First the samples were grounded to a fine powder with a mortar and paste. A pile of the grounded sample was put in the sample cup and chopped into place in the cup. Finally, the powder was pressed down and packed in the cup and placed inside the instrument (Bruker AXS D8 ADVANCE VARIO powder diffractometer, $\text{CuK}\alpha_1=1.54058 \text{ \AA}$). The samples were run once over a 2θ range of 5° – 55° with a step size of 0.05° and an acquisition time per step of 1 second. Both the thermal treated and untreated samples were analyzed. The results from the scan were used to do a qualitative analysis of the samples. The qualitative analysis was done using the software for the XRD (Bruker EVA software) and with the help of the database in the program (ICDD PDF-4+).

4.4.2 Quantitative analysis

The samples were grounded in the same way as in the qualitative analysis. Except that the samples were also mixed with an internal standard of gypsum to be able to quantify the samples. In the grounded powder, 10% by mass of internal standard was mixed to a homogeneous mixture. The samples were scanned three times over a 2θ range of 26° – 30° with a step size of 0.02° and an acquisition time per step of 2 seconds. The results from the scans with the internal standard were used to do the qualitative analysis. The XRD-graphs were scaled and lined up so that the peak height and position of the internal standard were the same for all measurements of all the samples. The peak height and area of the other compounds in the samples could then be determined and used for quantification. Hence the ratio of the compounds between the samples could be determined as well.

4.5 Grain and Filler density and water absorption

The grain density was determined by using the Swedish standard SS-EN 1097-6 annex A4. The grain density was determined on the recycled fractions 0.125 to 8 mm and on standard aggregates, CEN-Normsand EN 196-1, using a glass pycnometer.

First the pycnometer was weighed empty and then approximately 250 g of the fraction were weighed and put inside the pycnometer. The pycnometer and the material were weighed together and some deionized water was added to the pycnometer and set aside for at least one hour. After one hour, additional water was filled up to the calibration mark and weighed and the temperature of the water was measured. This was repeated for every fraction.

The density was calculated with the equation.

$$\rho_p = \frac{(M_2 - M_1)}{V - (M_3 - M_2)/\rho_w}$$

Equation 1. M_1 is the mass of the pycnometer in grams, M_2 is the mass of the pycnometer and material in grams, M_3 is the mass of the pycnometer, material and water in grams, ρ_p is the particle density of the material, ρ_w is the density of the water, V is the volume of the pycnometer in ml.

The standard method SS-EN 1097-7 was used to determine the filler density of the fraction <0.075 and 0.075-0.125 mm. Small glass pycnometers were used.

50 g of the fraction were weighed and then 10 g of the sample were put inside three pycnometers each and filled with water covering the samples. The same procedure was repeated with the second fraction. The pycnometers were placed in a vacuum chamber and the pressure was set to 0.3 mbar for 30 minutes. After 30 minutes, the pycnometers were placed in a water bath at 25 °C for one hour and the pycnometers were filled up with water. The pycnometers were then weighed and the filler density calculated.

4.6 Casting, pressure test, slump flow test

Four different concrete mixtures with different proportions of cement (Table 1) were casted and each mixture was made twice and casted twice to obtain six prisms. The cement that was used was Skövde Byggcement from Cementa in Skövde. In mixture 2, the filler that was used was limes 25 (limestone filler). The aggregates that were used in the mixtures were 0.125-2 mm Normsand and Råda 2-4 mm (aggregates from Råda gravel pit outside Lidköping) mixed 50/50.

Mixture	Proportions of cement in the mixtures
1	100% Skövde byggcement
2	50% Skövde byggcement & 50% limes 25
3	75% Skövde byggcement & 25% Fine fraction
4	50% Skövde byggcement & 50% Fine fraction

Table 1. The different mixtures that were used in the mechanical and physical testing of the recycled cement.

The mixtures were made according to the Swedish standard SS-EN 196-1. 1350 g of ballast, 250 g of cement and 125 g of water were mixed together following the instructions in SS-EN 196-1. Before the concrete was poured into the molds, the slump flow of every mixture was measured. The slump flow is measured on the newly mixed concrete by forming the concrete into a cone on a metal plate. The metal plate is exposed to impact shocks one time per second for 15 seconds. The diameter of the concrete cone, which has flown out to a circle, is then measured. The concrete was poured into the mold. When the mold was half-filled it was vibrated for one minute before the rest of the concrete was poured into it. The mold was vibrated once more, for one minute. The mold was covered with a glass plate and placed in an environmental chamber and the concrete was allowed to cure for 24 hours. After 24 hours, the prisms were taken out of the molds. Two prisms were used right away in the mechanical and physical testing of the prisms to get the Day one results. The four other prisms were set aside in a water bath to be used later for the tests on Day 7 and on Day 28. Before the compressive strength test, two of the prisms were divided into two halves. The four halves were tested to the breaking point.

5. Results

5.1 Heating and weighing of the concrete

At 120 °C, the moisture in the concrete will evaporate. As shown in Table 2, the average moisture content in the concrete is 2.41% of the mass. This shows that the concrete was quite dry. It should be mentioned that the concrete has been stored inside for some months and if a newly demolished concrete had been used instead the percentage of moisture content might have been higher. Between 120-400 °C the crystalline water, which is bound in the concrete, will evaporate and some of the organic materials could burn. The water content in the concrete, the moisture and the crystalline water, does not compose a high percentage of the concrete mass. The calcium hydroxide in the concrete will lose water between 400-650 °C and most of the organic materials will burn off. The loss of water will make the concrete more porous and it will make the cement and the aggregates easier to separate from each other. Between 650-1000 °C the carbonates, probably mostly calcite, in the concrete will lose carbon dioxide and form oxides. In Table 2, the standard deviation for the temperature interval of 120-400 °C is quite high. This is probably due to that some of the aggregates came loose and fell off during the handling of the samples during the test and gave a larger weight loss.

Temperature (°C)	Average weight loss (%)	Standard dev
20-120	2.41	1.72
120-400	6.67	4.96
400-650	5.74	2.1
650-1000	6.85	N/A

Table 2. The results from the heating and weighing of the concrete. The table shows the average loss of mass in percent at the different temperatures. The percentage loss of mass is based on the original weight before the thermal treatment.

5.2 Crushing and separation of cement and aggregates

The first grain curve (Figure 1) shows mass percentages for the different fractions of the thermal treated concrete and in the second grain curve (Figure 2) the non-thermal treated concrete is presented. The fine fraction, in the thermal treated concrete, that has been separated from the aggregates is roughly 8.3 % and the cement in a typical concrete mixture is about 10-15 %. The cement that has not been separated is still bound to the aggregates mainly in depressions and cracks on the surface (See Image 5).

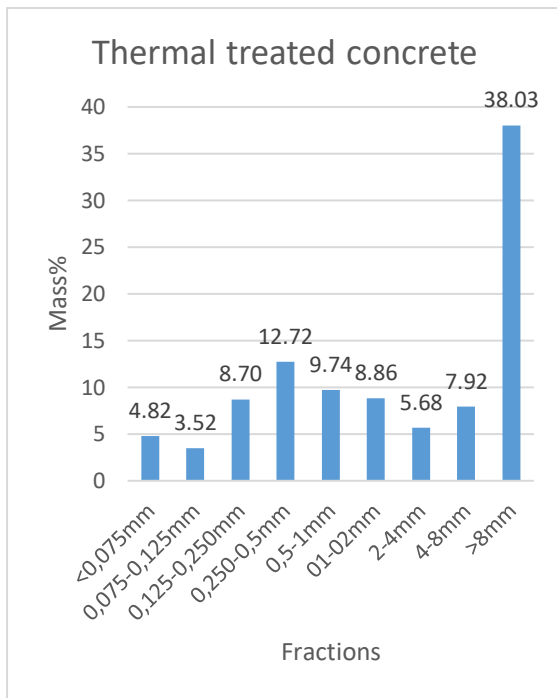


Figure 1. Particle size distribution from sieving of the thermal treated concrete after milling.

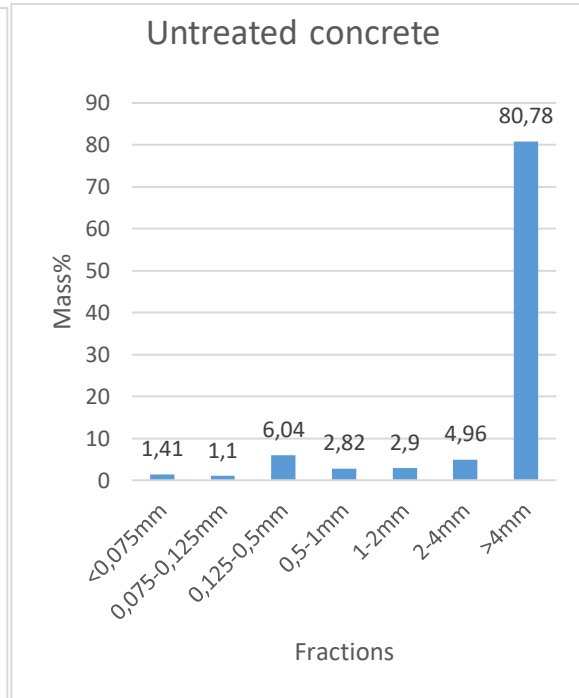


Figure 2. Particle size distribution from sieving of the un-treated concrete after milling.

Also in the largest fraction of aggregates, the 8 mm and larger, there is some cement and fine aggregates still bound to the largest aggregates. This is probably due to the limitation of the mill that was used in the process. Because the small size of the mill containers and the size of the larger fractions, the force that is needed to mill the larger fractions cannot be generated. If compared with the non-thermal concrete, only around 2.5 % cement has been separated from the aggregates. This indicates that the thermal treatment makes the cement and aggregates more separable from each other. Also, the portion of the fractions 4 mm and larger is greatly larger in the non-thermal treated concrete, which indicates that most of the smaller fractions are still bound together, forming larger pieces of concrete. Again, the force that is needed to mill the larger fractions, in the non-thermal treated concrete, cannot be generated, due to the limitations of the mill. The problem is that the force that is needed to crush the cement will probably crush or damage the aggregates as well. When the concrete is thermal treated the force threshold for the cement is lowered but not for the aggregates.



Image 4. Non-washed aggregates from the thermal treated concrete. In the top left corner is the fraction 0.125-0.5 mm and next to it is the fraction 0.5-1 mm. Down in the left corner is the 1-2 mm fraction, and next to it the 2-4 mm fraction.

Image 4 and 5 show the difference between washed and non-washed aggregates from the thermal treated concrete. On the non-washed aggregates there is a thin coat of cement dust that covers the aggregates. On the aggregates washed with deionized water the dust was removed, and the colors become more prominent. The aggregates were weighed before and after washing and the coat of dust is less than 0.1 % of the mass and therefore negligible. The amount of dust coat was similar for all of the fractions. As mentioned earlier, the cement that is still bound to the aggregates, after being washed, is mainly bound in the depressions and cracks of the aggregates. This can be observed in Image 5, especially in the fractions 1-2 mm and 2-4 mm. If compared with the non-thermal treated concrete (Image 6) the cement is not only bound in the depressions and cracks. The cement is bound to and covers most of the surface of the aggregates and almost none of the color of the aggregates is visible. The aggregates from the non-thermal treated concrete also have a smoother look, than the thermal treated aggregates which still have the rougher edges of crushed stone; this is due to the fact that more cement is still bound to the aggregates.



Image 5. Washed aggregates from the thermal treated concrete. In the top left corner is the fraction 0.125-0.5 mm and next to it is the fraction 0.5-1 mm. Down in the left corner is the 1-2 mm fraction, and next to it is the 2-4 mm fraction.



Image 6. Washed aggregates from the non-thermal concrete. In the top right-hand corner is the fraction 0.125-0.5 mm and next to it is the fraction 0.5-1 mm. Down in the left corner is the 1-2 mm fraction, and next to it is the 2-4 mm fraction.

5.3 X-ray diffraction analysis on the crushed concrete

The results from the two XRD analysis, qualitative and quantitative analysis, are shown in this section.

5.3.1 Qualitative XRD analysis

Figure 3 shows a typical example of the results from the qualitative analysis. With the help of the database in the XRD software, the different peaks have been determined. For example, in Figure 3, the largest peak was determined to be quartz in the sample.

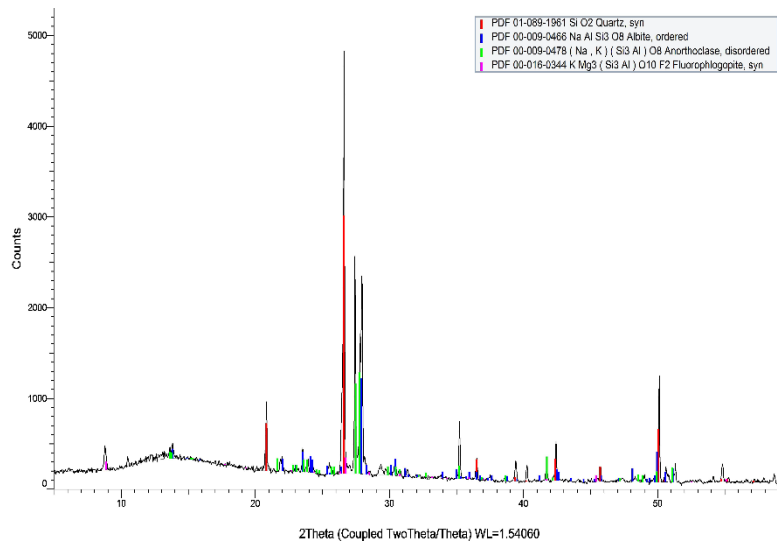


Figure 3. Qualitative XRD analysis of the 0.125-0.25mm fraction of the thermal treated concrete. The analysis shows that the fraction contains quartz, calcite, feldspar and traces of other minerals.

The results from the other fractions of the thermal treated concrete show that in the smallest fraction, <0.075 mm, the peak for calcite is higher while the peak for quartz is lower. When the particle size increases, in the samples, the peak for quartz increases too while the peak for calcite decreases. This indicates that in the larger fractions there are less cement still bound to the aggregates and the two fine fractions mostly contain cement and that a good separation was achieved between the cement and aggregates. On the other hand, the tests made on the non-thermal treated samples (Figure 4) show that the peaks for calcite and quartz are almost the same for the different fractions. This indicates that a good separation was not achieved. The analysis show that the fractions contain quartz, calcite, feldspar and other trace minerals. Using the software, and the databases in the software, does not give an entirely accurate analysis. Some of the difficulties, to get an accurate result, is that some of the peaks lay so close to each other that they will overlap and interfere. Also, the results from the qualitative analysis only give an indication on the concentrations of the different minerals in the samples. To get a more accurate result, a quantitative analysis, with an internal standard, needs to be made.

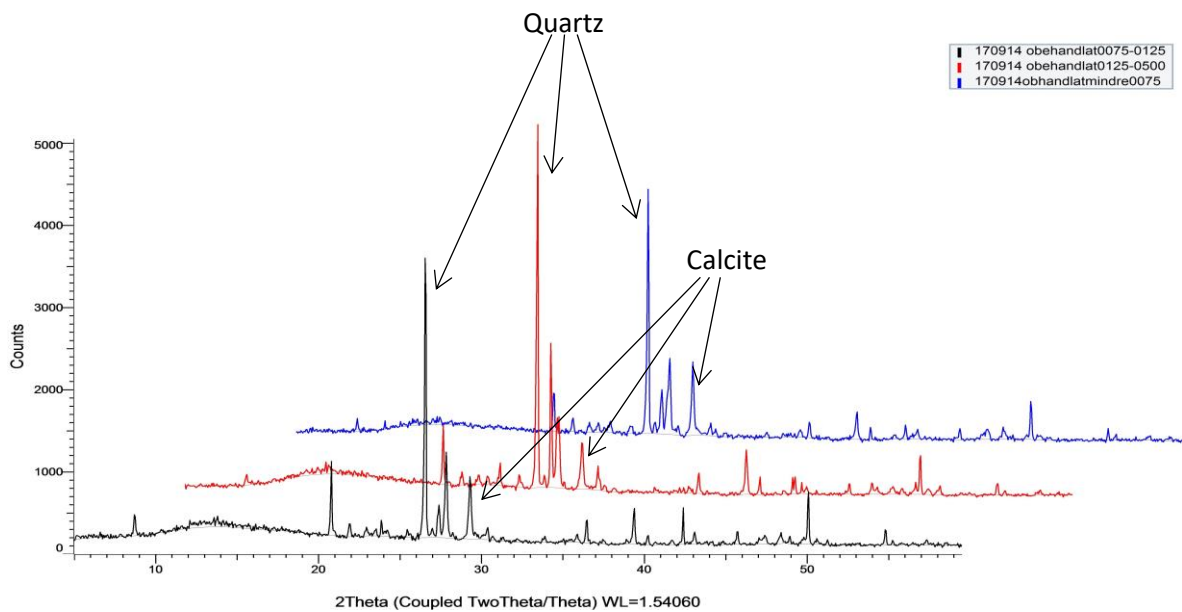


Figure 4. Qualitative XRD analysis of the fractions of the non-thermal treated concrete show that the fractions have similar concentrations of quartz and calcite. The three graphs show the smallest fractions, blue <0.075 mm, black 0.075-0.125 mm and red 0.125-0.5 mm. The graphs are shifted on the z-axis.

5.3.2 Quantitative XRD analysis

The two Figures (5A and 5B) show the results from the quantitative analysis from the XRD on the thermal treated and non-thermal treated concrete. The levels of quartz and calcite in the different fractions of the thermal treated and non-thermal treated concrete are shown. The calcite is found in the cement paste and the quartz in the aggregates. In the first graph A, for thermal treated concrete, there is a clear trend showing that with increasing fraction sizes, the quartz will increase and the calcite will decrease. This shows that there has been a separation of the cement from the aggregates. Whereas in graph B, the non-thermal treated concrete, there is no trend. Here, the levels of quartz and calcite are more irregular and show a higher amount of quartz in the fine fractions and a higher amount of calcite in the larger fractions. The higher levels of quartz in the fine fractions are probably due to, as mentioned before, the force that was needed in the crushing of the non-thermal treated concrete, broke or damaged the aggregates too. Also as mentioned before, the fact that there are higher levels of calcite in the larger fraction is because more cement is still bound to the aggregates.

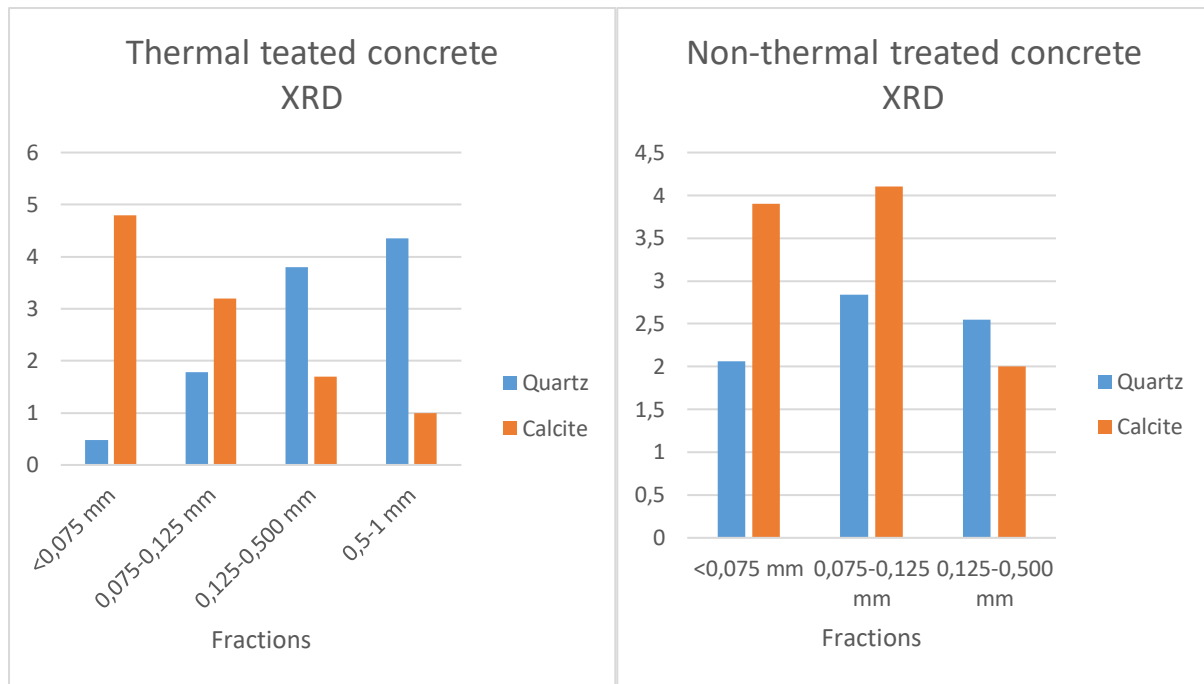


Figure 5. The concentration of calcite and quartz for each fraction. A: The quantitative analysis results for the thermal treated concrete. B: The quantitative analysis results for the non-thermal treated concrete. The x-axis shows the different fractions of the samples that were analyzed and the y-axis shows the peak height for the calcite and the peak area for the quartz. The samples have been normalized against the internal standard.

5.4 Grain and Filler density and water absorption

Table 3 shows the different grain density and water absorption for the different aggregates. The water absorption tests were performed on the fractions 2-4 mm, 4-8 mm and on a mixture of the fractions 0.125-0.250 mm, 0.250 mm-0.5 mm, 0.5 mm-1 mm, 1-2 mm in equal parts by mass.

Fraction	0.125-0.250	0.250-0.5	0.5-1	1-2	2-4	4-8	0.125-2	Normsand
Grain density (g/cm ³)	2.56	2.581	2.701	2.709	2.68	2.32	2.68	2.63
Water absorption	N/A	N/A	N/A	N/A	4.8 %	4.9 %	6.5 %	N/A

Table 3. Table of the grain density and water absorption of the different fractions of aggregates.

As can be seen in the table, the density of the recycled aggregates is close to the density of the Normsand that is the standard reference of aggregates. The grain density is an average of the individual grains in the fractions. The water absorption is around 5-6 % for the recycled aggregates. If compared with earlier works the water absorption is around 10-12 %, if the concrete has not been thermal treated [3]. In Table 4, down below, are the results for the filler density tests done on the cement fractions. Compare to grain density, filler density is an average of the total air free mass of the cement fractions, not the individual grain.

Fraction	<0.075	0.075-0.125
Filler density (g/cm ³)	2.80	2.75

Table 4. The filler density of the two cement fractions.

5.5 Casting, pressure test and slump flow

Table 5 down below shows the result of the slump flow test done on the different concrete mixtures. As shown in the table, in a mixture with a higher proportion of recycled fine fraction, the slump flow will decrease and will become firmer if compared to the reference mixture.

Mixture	Slump flow
100 % Skövde bygg	210 mm
50% Skövde bygg and 50 % limes 25	210 mm
75 % Skövde bygg and 25 % fine fraction	182.5 mm
50 % Skövde bygg and 50 % fine fraction	147.5 mm

Table 5. The slump flow results of the different concrete mixtures.

In the next table, Table 6, the results from the mechanical and physical tests that were made on the casted prisms are shown. The table shows that if 25 % fine fraction is mixed with 75 % Skövde bygg the concrete, after 7 days, still has around 83 % of the reference mixture's total strength. This ratio between recycled cement and new cement in a mixture may be used in the construction of new buildings.

Mixture/Day	1D	7D	28D
100 % Skövde bygg	23.8	45.8	53.3
50 % Skövde bygg and 50 % chalk	7	14.4	16.7
75 % Skövde bygg and 25 % fine fraction	18.9	37.9	44.6
50 % Skövde bygg and 50 % fine fraction	14.1	31.6	36.5

Table 6. Compressive strength test for the different mixtures of concrete. The results are displayed in unit N/mm².

6. Discussion

The thermal treatment of concrete, at 650 °C, prior to crushing will make the separation of the cement from the concrete much easier compared to not thermal treating the concrete. The concrete loses its characteristic of hardness and turns into a fragile composite that can be destroyed by hand without the use of great strength due to the heat treatment. The lab-scale separation method used was rather simple. Some of the tools were somewhat crude but appropriate for the aim of this study. However using more advanced crushing and separation techniques might give more effective results.

The XRD method was found to be well-suited in the quantitative and qualitative analysis of the different crystalline phases in concrete. The images taken by the optical microscope also provide a clear view of the remaining cement volumes on the aggregates, which help to understand the effectiveness of the separation.

Only one type of demolition concrete was used in this study and it might not entirely be representative for demolition concrete in general. To get a more representative result, more types of concrete, from different types of constructions, and larger quantities need to be tested.

The heating and weighing show that the concrete that was used in this study was quite dry, because it had been stored indoor for some months. Therefore, not a large amount of moisture was needed to evaporate in the heating step. If a more fresh or wet demolition concrete had been used, more energy would be required to evaporate the moisture. A possible solution to save and reuse that energy on an industrial scale is to use the condensate in a series of heat exchanger, then using the recovered energy to e.g. pre-dry the concrete before heating

The results from the mechanical tests on the different concrete mixtures (Table 4) show that it is possible to mix the newly recycled cement into new concrete and not losing much of the strength of the concrete. With this kind of concrete mixture we think it would be quite possible to construct new buildings, such as residential buildings, that do not require the highest grade of concrete. In addition, the slump flow test shows that a higher percent of recycled cement in the mixture makes the concrete more firm and will also lower the workability of the concrete. It should be mentioned that no plasticizers or other additives were used. The use of plasticizers or additives could increase the workability of the concrete and could also increase the final strength of the concrete. We also used a high percentage of recycled cement, 25 % and 50 %, in the mixtures. A more reasonable percentage of recycled cement in the industry could be around 10 %, and with a lower percentage the strength and the workability of the concrete would probably be better.

The effectiveness of the separation was lowered due to the limitations of the equipment, in particular the steel ball mill. It was not possible to mill the largest fractions effectively enough to obtain a higher yield of fine fraction from the concrete. To increase the effectiveness of the separation, a larger mill is needed that is able to generate a stronger force to mill the largest

aggregates. However, a problem with an increase in force is that it could damage the smallest aggregates and cause a higher contamination of the fine cement fractions.

If this process could be implemented on an industrial scale, the environmental gain could be large. By using recycled cement in new concrete, the need to produce new cement would be lowered and therefore the carbon dioxide emissions from the production would be lowered too. The need to produce new cement could be lowered by around 4 percent (in Sweden) if all the demolition concrete could be recycled [12]. To lower the new production of cement by 4 percent does not seem very high, but compared to the quantities of cement that is produced, not only in Sweden but around the world, the 4 percent will be massive if seen in mass and carbon dioxide emission.

More research is needed to fully understand the possible environmental benefits of an implementation of a process based on recycling of concrete. Because one of the disadvantages to recycle the concrete is that it might need to be transported long distances in order to be recycled. That would require large amounts of fuel just to transport concrete. Another disadvantage is the heating of concrete to 650 °C. On a larger scale that requires large amounts of energy. Therefore, the environmental gains from lowering the emissions in the production could potentially be lost in the treatment of the demolition concrete.

An ideal solution to lower the need of transporting the concrete longer distances is to build mobile treatment facilities at the demolition site and to separate the cement from the aggregates on site. The cement could then be transported to the mixing location and the aggregates could be used as landfill. This would greatly lower the transported mass from the demolition site to only around 10 % of the total weight of the concrete, because 10 % of the concrete is recycled cement.

A possible negative effect from moving the concrete treatment facilities from a more remote location, such as an industrial area, to the demolition area is that it could cause health risks, to workers and the local population, such as dust and particle pollution in the air. A compromise could be to place the mobile treatment facilities in the outskirts of the city. It would not completely eliminate the need of transport but lower it significantly. Also, that would not place the treatment facilities in the most densely populated area and limit the potential health risks.

7. Conclusion

The results from the XRD and the images from the optical microscope show that a thermal treatment of concrete will

- increase the separation efficiency of the aggregates and cement.
- give less contamination of aggregate material in the fine cement fraction (<0.075-0.125 mm).

Furthermore, the grain curves show a larger yield of cement fractions in the thermal treated concrete compared to the non-thermal treated concrete.

The results from the mechanical and physical tests show that the water absorption increased in the recycled materials compare to new standard materials and that the workability will decrease with a higher percentage of recycled concrete.

The mechanical test of the prisms, with 25 % fine fraction, show that the final strength of the concrete does not differ much from the reference test. This mixture with the proportions of 25 % recycled cement and 75 % new cement could possibly be used in new constructions without great loss of strength and durability.

8. Future research

- Do an LCA over the recycling process of concrete to examine the environmental gains.
- Investigate how to scale up this process for more practical uses in the industry and do a pilot test.
- Examine if it is possible to reactivate the cement fractions to make them more suitable to be reused as newly produced cement.

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