Feasibility study of construction and demolition waste to sequestrate carbon dioxide through direct aqueous mineral carbon capture

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The direct aqueous mineral carbon capture (MCC) of construction and demolition waste (C&DW) using modeled CO_2 flue gas was investigated under ambient laboratory conditions. During the C&DW recycling into aggregates, a fine-hydrated C&DW byproduct is produced. This byproduct is not suitable for re-use since it reduces the quality of recycled aggregate. Fine-hydrated C&DW is a potential agent for CO_2 sequestration due to its calcium content. Calcium and CO_2 form thermodynamically stable calcium carbonate ($CaCO_3$). The goal of the paper was to determine the efficiency of borehole water and acid mine drainage (AMD) as a calcium leaching agent. To estimate the carbonation capacity of sorted C&DW and to characterise the carbonated products. At a solid-to-liquid ratio of 1:10, 328 mg/L of calcium was extracted from the sorted C&DW using borehole water, whereas 85 mg/L of calcium was extracted from sorted C&DW using AMD. Therefore, fresh borehole water was tested in a direct aqueous MCC process. Carbonation increased the calcium carbonate content in the sorted C&DW from 18.03 wt% to 27.09 wt%. Corresponding CO_2 uptake was 10.55 g-CO_2 per 200g sorted C&DW. The results from this study are comparable to results reported in the literature.

INTRODUCTION

The estimated CO_2 emissions from the cement and concrete sector have been well documented. Reportedly, China, India, and the USA were the three major CO_2 emitters in 2021. Globally, the cement and concrete sector emits approximately 7-8% of CO_2 (Althoey *et al.*, 2023; Miller *et al.*, 2022). In Africa, South Africa is ranked as the third major emitter of CO_2 from the cement and concrete industry with Egypt and Nigeria as first and second, respectively. It is estimated that cement and concrete production in South Africa is responsible for about 1.7% of the national CO_2 emissions (Parker, 2022).

CO_2 emissions from the cement industry are divided into two categories, (i) direct emissions and (ii) indirect emissions. Indirect emissions are non-process related emissions derived from activities such as transportation and generation of electricity. Direct emissions are process-related emissions that result from fossil fuel combustion and calcination process.

Direct emissions account for about 80% of total CO_2 emissions, while indirect emissions account for the remaining 20% (Lowitt, 2020). Given that 80% are direct emissions, it is estimated that in South Africa, 1.36% of the total CO_2 emissions are derived from fossil fuel combustion and kiln calcination processes. These CO_2 emissions are currently unavoidable, and our research activities are evaluating routes to reduce these emissions.

Work conducted on geopolymer cement (GPC) revealed that a novel GPC has superior properties compared to ordinary Portland cement (Naghizadeh & Ekolu, 2017; Singh *et al*., 2020) when employed as a binder in concrete. Furthermore, GPC is regarded as having low CO_2 emission compared to ordinary Portland cement (Naghizadeh & Ekolu, 2017), however, its commercial application is still under investigation (Tau *et al*., 2023). Literature review showed various applications of alternative cementitious materials (ACM) as a partial replacement for Portland cement clinker to reduce CO_2 emissions (Sinngu *et al*., 2023; Tau *et al*., 2023). Up to 15% metakaolin (Sinngu *et al*., 2023; Tau *et al*., 2023) and up to 70% ground-granulated blast-furnace slag (Miller *et al*., 2022; Tau *et al*., 2023) were tested as ACM with the aim of improving the compressive strength of concrete along with the reduction in CO_2 emissions. Miller *et al.* (2022) demonstrated that ACMs have the potential to reduce cement and concrete CO_2 emissions by approximately 2.8%. According to Parker (2022), AfriSam; a South African manufacturer of construction materials, utilizes up to 70% ACM resulting in CO_2 emissions of 598 kg per tonne of cement produced. These emissions are lower than South African average of 671 kg and lower than the global average of 641 kg of CO_2 emissions per tonne of cement produced. However, the addition of ACM does not bring the CO_2 emissions under acceptable limits, thus further CO_2 reduction measures are required (Tau *et al*., 2023).

Mineral carbon capture (MCC) is a promising technology to capture anthropogenic CO_2 (Xuan *et al*., 2016). MCC mimics the weathering process of calcium-containing minerals. Calcium-containing minerals are carbonised at an accelerated rate producing a stable product calcium carbonate (Vanderzee & Zeman, 2018). The reaction mechanism initiates with the dissolution of CO_2 in an aqueous solution to form carbonic acid followed by the dissolution of calcium (Ca) or magnesium (Mg) metals extracted from alkaline solid material. Dissolved CO_2 and metal ions react to form thermodynamically stable carbonates. The reaction mechanism is as follows:

$$CO_{2(g)} + H_2O_{(l)} \rightarrow CO_3{}^{2-}{}_{(l)} + 2H^+{}_{(l)} \qquad [1]$$

$$M(OH)_{2(s)} + H_2O_{(l)} \rightarrow M^{2+}{}_{(l)} + 2OH^-{}_{(l)} + H_2O_{(l)} \qquad [2]$$

$$CO_3{}^{2-}{}_{(l)} + M^{2+}{}_{(l)} \rightarrow MCO_{3(s)} + H_2O_{(l)} \qquad [3]$$

where M stands for either Ca or Mg.

The reaction mechanism above shows that dissolution and precipitation are the fundamental processes in MCC (Ho *et al*., 2020). Parameters such as temperature, solid-to-liquid ratio, particle size of alkaline materials, CO_2 pressure, and CO_2 flow rate play a critical role in the reaction performance of the mineral carbonation process. Ho *et al.* (2020) successfully demonstrated direct aqueous MCC at ambient conditions. The authors used waste concrete fines at various solid-to-liquid ratios with constant particle size (≤ 200 μm). The study reported a CO_2 uptake efficiency of 0.19%, 0.20%, and 0.22% CO_2 per gram of waste concrete fines for solid-to-liquid ratios of 10 g/L, 25 g/L, and 50 g/L, respectively. Although there is no significant difference in CO_2 uptake efficiency, there was a notable increase in the CO_2 uptake mass. Their result showed that CO_2 removal increased with solid-to-liquid ratio: 10 g/L (3.71 g), 25 g/L (10.04 g), and 50 g/L (21.54 g). These findings on the increase in CO_2 uptake mass with an increase in the mass of concrete waste are in line with MCC studies conducted by Sorrentino *et al*., 2023. Therefore, the MCC process using alkaline waste presents a shared benefit in terms of the reduction of CO_2 emissions as well as waste re-utilisation.

Construction activities result in the generation of C&DW which is categorised as non-hazardous waste. During the recycling of C&DW into aggregate, hydrated C&DW fines are produced. C&DW fines are not suitable for re-utilisation due to the high water content that reduces the strength of the new concrete (Ho *et al*., 2020). Volumes reported for C&DW generation in South Africa are inconsistent, ranging from

1.5 million tonnes (Mt) (SAWI, 2021) to 21 Mt (Bao, 2023) annually. These inconsistencies may be attributed to poor waste management records at the local government level. MCC process opens an opportunity to promote a circular economy and sustainable development goals by redirecting C&DW from being landfilled, thus increasing the lifespan of the landfill sides (Department of Environment Forestry and Fisheries, 2021). To extract calcium from C&DW during direct aqueous carbonation, a low-cost solvent such as water can be used. Readily available borehole water used as a dust suppressant at the premises of the C&DW waste recycling plant is used as the Ca-extractant. Since South Africa is a water-scarce country (Gcasamba *et al.*, 2021), acid mine drainage (AMD) can serve as an alternative solvent for calcium extraction. AMD is amine-impacted acidic water with negative environmental impacts. It is produced by the oxidation of metal sulphides such as pyrite in the presence of water (Gcasamba *et al.*, 2021).

The objective of this study is to investigate construction and demolition waste (C&DW) as a source of calcium for the MCC process. Borehole water and AMD were tested as leaching agents for Ca contained in C&DW. Process products were characterised. This study presents the accelerated MCC using C&DW from the South African perspective. This process has the dual benefit of reducing CO_2 emissions at the same time as valorising the C&DW.

Materials and methods

Materials

A bulk of C&DW sample with an average particle size 33 mm was collected from a C&DW recycling plant located in the Western Cape Province, South Africa. Visual inspection revealed that it contained clay bricks, glass, tiles, cement bricks, and concrete waste. The bulk sample was divided into two representative samples where the original as-received sample was labeled "composite C&DW". From the as-received sample, cement bricks, and concrete waste were handpicked and labelled "sorted C&DW". This was done to examine the degree to which the presence of inert material (i.e., glass, tiles, metals) reduces the available calcium for carbonation. Prior to experiments, both sorted and composite C&DW were hammer-crushed and rod-milled down to particle size ≤ 100 µm. Solid samples before and after carbonation experiments were characterised by X-ray diffraction (XRD), X-ray fluorescence (XRF), and thermogravimetric analysis (TGA). The Ca-leaching agents (borehole water and AMD) were analysed using inductively coupled plasma-optical emission spectroscopy (ICP-OES) before and after carbonation experiments. The borehole water was sampled at the premises of the C&DW recycling plant. AMD was collected from the abandoned coal mines in Mpumalanga province in South Africa.

Methods

Mineralogical composition

Qualitative mineral determination on powder samples was conducted using Bruker D2 Phaser X-ray diffractometer (XRD). Measurement settings were adopted and modified from Sabai *et al.*, (2016). Minerals were identified using Panalytical X'Pert High Score Plus (PW3212) version 3.0 software.

Elemental composition

Elemental composition of the leaching agents and effluent water were determined by Varian ES730 ICP-OES. Both leaching agents employed in this study were filtered through a 0.2 µm filter. Prior to analysis, an aliquot was transferred into a volumetric flask and filled to the mark with 2% nitric acid (HNO_3). Both quantitative and qualitative analysis of the solid samples (i.e., feed and carbonated product) were determined by PANalytical Axios wavelength dispersive XRF spectrometer, equipped with a Rh end-window X-ray tube. Major elements were determined from the fused glass disk.

Thermal decomposition of solids

NETZSCH STA 449 *F5* thermogravimetric analyser (TGA) was used to measure calcium carbonate content in solids by determining the mass loss with respect to increasing temperature. Mass loss associated with calcium carbonate thermal decomposition (the effect is a CO_2 release) occurs in temperatures from 600 to 900 °C. TGA operating conditions were adopted from Sabai *et al.*, (2016).

Leaching experiment

Leaching tests were conducted to optimise carbonation reaction and to determine the Ca available for carbonation. These tests also examined the leaching potential of the two leaching agents employed in this study. The experimental set-up for the leaching test was assembled using an overhead stirrer with three blades and a glass beaker as the reactor. A 200g of solid sample was weighed into a beaker containing 2 L of leaching agent. The stirrer was set to 400 rpm and the leaching experiment proceeded for 60 min. pH was measured at 5 min, 20 min, 40 min, and 60 min of leaching time. The leaching time and sampling procedures were adopted and modified from Doucet (2010) and Ho *et al.*, (2021).

Direct aqueous mineral carbonation experiment

In this study, the lab-scale bubble column reactor used for direct aqueous mineral carbonation tests is identical to the set-up used by Ho *et al.,* (2020, 2021). The experimental set-up is depicted in Figure 1. The reactor has a capacity of 4 L.

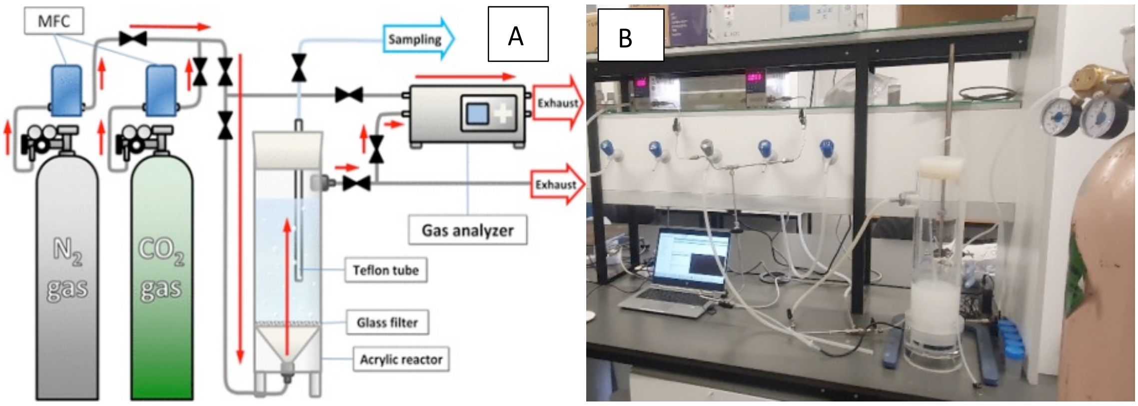

Figure 1. Lab-scale experimental set-up: (a) schematic diagram (Ho et al.*, 2020), (b) set-up at the Chemical Engineering Department, Cape Peninsula University of Technology.*

A 32 vol.% CO_2 balanced with nitrogen (N_2) was used to calibrate the ABB (EL 3000) gas analyser. To model exhaust fumes from South African cement industries containing 20 vol.% CO_2, a mass flow controller (MFC) was used to regulate the flow rates of 99% CO_2 and 99% N_2, procured from Air Liquide. CO_2 was set at 0.8 L/min and N_2 at 3.2 L/min, resulting in a total flow rate of 4 L/min. 2L of fresh leaching agent was transferred into the reactor, and the modeled exhaust fumes (at 4 L/min), were bubbled through until the solution became saturated, indicated by similar CO_2 concentrations at the reactor inlet and outlet. A 200 g of C&DW (equivalent to solid-to-liquid ratio 1:10) was then quickly introduced to minimise CO_2 loss to the atmosphere. The experiment lasted 60 min, monitoring CO_2 levels at the reactor outlet and pH within the reactor. Afterward, the solid products were dried at 105 °C and characterised. Liquid samples were filtered for non-metal and metal analysis, with those for metal analysis acidified with 3 M HNO_3 and stored at 4 °C.

Results and discussion

Characterisation of feed materials

Table I shows the composition of the fresh leaching agents. AMD exhibited higher concentrations of Ca, Fe, Mg, and SO_4 compared to borehole water. Cr and P were below the detection limits of ICP-OES. Notably, the high SO_4 concentration in AMD can react with Ca to precipitate gypsum under near-neutral to alkaline conditions (Thisani *et al.*, 2022), potentially reducing the availability of Ca for mineral carbonation. However, studies by Gcasamba *et al.*, (2021) and Mahedi *et al.*, (2021) indicate that cationic leaching of Ca occurs during the treatment of AMD with C&DW.

Table I. Composition of fresh leaching agents determined by ICP-OES

	Concentration (mg/L)													
Leaching agent	**Ca**	**K**	**Mg**	**Na**	**Si**	**Al**	**P**	**Cr**	**Fe**	**Mn**	**Pb**	**Zn**	**Cl**	**SO_4**
Fresh borehole water	63.1	4.7	3.3	9.7	7.6	0	0	0	0	0	0	0	20.5	19.1
Fresh AMD	430	46.7	436	56.1	50.1	430	0	0	3201	88.4	0.2	8.3	110	3561

Figure 2 depicts the XRD diffractogram of sorted and composite C&DW. Sorted C&DW contains portlandite mineral ($Ca(OH)_2$), which is absent in the composite C&DW. Portlandite is highly reactive during mineral carbonation of C&DW (Ho *et al.*, 2021), readily dissolving in water to release Ca necessary for the process. Both C&DW samples contain quartz, which, according to Wang *et al.*, (2024), can form a layer that inhibits the reaction of Ca with CO_2. Additionally, both samples contain calcite ($CaCO_3$), which, as a carbonate, is unavailable for the mineral carbonation process.

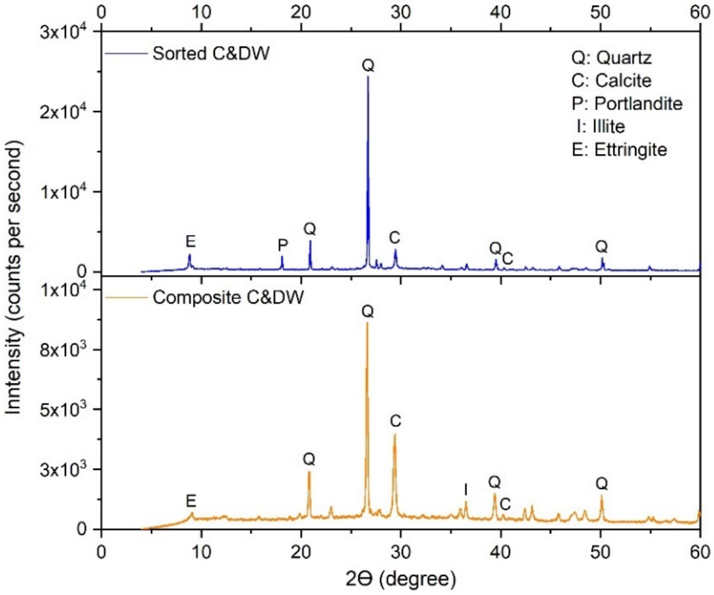

Figure 2. XRD diffractogram of sorted and composite C&DW.

Table II shows the elemental composition of sorted and composite C&DW. Composite C&DW contained lower quantities (17.99%) of CaO compared to sorted C&DW (23.45%). Sorted C&DW also had SiO_2 (46.39%), MnO (0.04%), Fe_2O_3 (1.97%), and SO_3 (0.56%), while composite C&DW contained SiO_2 (41.89%), MnO (0.09%), Fe_2O_3 (3.07%), and SO_3 (0.76%). Both XRD and XRF data confirmed that sorting C&DW increases the Ca content, which is essential for mineral carbonation processes.

Table II. Elemental composition of sorted and composite C&DW determined by XRF analysis

Analyte	**Sorted C&DW (%)**	**Composite C&DW (%)**
SiO_2	46.39	41.89
Al_2O_3	4.28	7.78
Fe_2O_3	1.97	3.07
MnO	0.04	0.09
MgO	0.68	1.02
CaO	23.45	17.99
Na_2O	0.33	0.39
K_2O	0.59	0.92
SO_3	0.56	0.76
LOI	14.37	17.06

TGA analyses were conducted to study the thermal decomposition of the alkaline C&DW material. Sorted C&DW released 7.93 wt% of CO_2 while composite C&DW released 8.94 wt% of CO_2. Volatile matter content, calculated as the difference between the LOI values (14.37% and 17.06%) and water content (6.16% and 7.44%) of C&DW depends on the mineralogical and elemental composition of the sample. Sorted C&DW had a volatile matter content of 8.21 wt% while the volatile matter content of composite C&DW was 9.62 wt%. Calculated volatile matter content was in agreement with the CO_2 released during TGA analysis. These results indicated that the calcium carbonate was the major contributor to volatile matter in both C&DW samples. By taking CO_2 data from TGA analysis, Equation 4 was employed to determine the concentration of calcium carbonate ($CaCO_3$) present in C&DW samples:

$$CaCO_3\ in\ C\&DW(wt.\%) = CO_2\ (wt.\%) \times \frac{molar\ mass\ CaCo_3}{molar\ mass\ CO_2} \qquad [4]$$

Weight percent of $CaCO_3$ in C&DW was an input for Equation 5 to determine the Ca (wt.%) in C&DW present as $CaCO_3$:

$$Ca\ in\ C\&DWas\ CaCO_3\ (wt.\%) = \%CaCO_3 \times \frac{molar\ mass\ of\ Ca}{molar\ mass\ of\ CaCO3} \qquad [5]$$

From the XRF data, Equation 6 delivered total Ca (wt.%) in C&DW samples:

$$Ca\ total\ in\ C\&DW\ (wt.\%) = \%CaO\ x\ \frac{molar\ mass\ of\ Ca}{molar\ mass\ of\ CaO} \qquad [6]$$

Total Ca (wt.%) in C&DW sample (Equation 6) and Ca (wt.%) in C&DW present as $CaCO_3$ (Equation 5) were inputs for Equation 7 to determine the Ca (wt.%) available for MCC process:

$$Ca\ (wt.\%) available\ for\ MCC = Equation\ 6 - Equation\ 5$$
[7]

Knowing the available Ca, Equation 8 was employed to determine the theoretical carbonation capacity (g-CO_2) of the C&DW samples:

$$Theoretical\ carbonation\ capacity\ (gCO_2/g\_C\&DW) = \frac{Available\ Ca}{100} \times \frac{molar\ mass\ CO_2}{molar\ mass\ Ca} \qquad [8]$$

Results of the calculations above are presented in Table . Theoretical carbonation capacity of sorted C&DW is 0.107 g-CO_2/g-C&DW sample, which is twice that of composite C&DW. Doucet, (2010) stated that a minimum of 10% available Ca in alkaline waste is generally needed for a viable MCC process. Based on the theoretical carbonation capacity, available Ca, and data from XRD and XRF analyses, sorted C&DW was selected for extensive leaching and carbonation experiments due to its superior characteristics compared to composite C&DW.

Table III. Theoretical carbonation capacity

Feed material	**Total Ca (wt.%) in C&DW samples**	**Ca (wt.%) in C&DW present as $CaCO_3$**	**Ca (wt.%) available for MCC**	**Theoretical carbonation capacity (g-CO_2/g-C&DW)**
Sorted C&DW	17	7	10	0.107
Composite C&DW	13	8	5	0.052

Leaching tests

Initial pH of AMD was 2, rising to ~11 within 5 min, where it stabilised for the duration of the leaching test. Borehole water had an initial pH of 8, increasing to 12.5 within 5 min and remaining stable thereafter. The final pH levels of both leaching agents were in the carbonate zone (> 10). Doucet, (2010) stated that pH >10 and sufficient concentrations of Ca and Mg play a critical role to buffer the system which allows continuous dissolution of CO_2 and precipitation of solid calcium carbonate. Figure 3 shows the net chemistry change of leaching agents after the leaching tests with sorted C&DW. Borehole water extracted 328 mg/L of Ca at a solid-to-liquid of 1:10, while AMD extracted 85 mg/L of Ca under the same conditions.

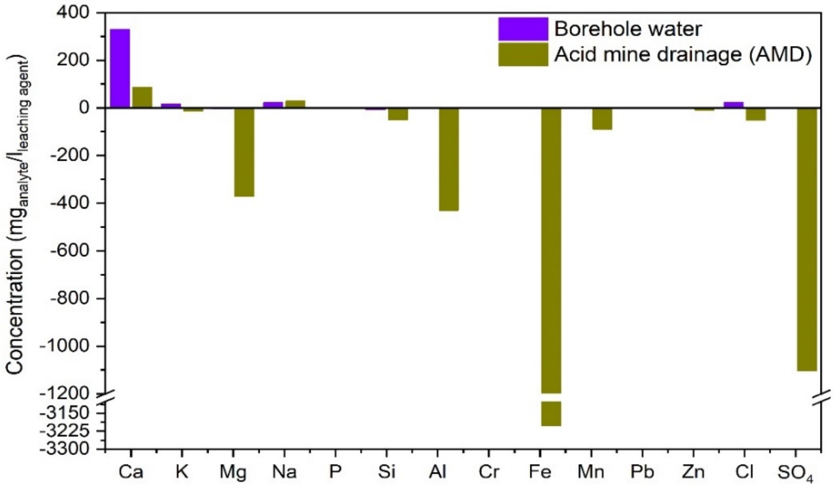

Figure 3. Net chemistry changes of leaching agents after leaching tests with sorted C&DW (positive y-values: elements extracted from C&DW and negative y-values: elements precipitated out of leaching agents).

Less calcium leached by AMD was attributed to the precipitation of gypsum ($CaSO_4 \bullet 2H_2O$) observed in the solid residue after leaching (XRD diffractogram, not shown). Both ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12} \bullet 26H_2O$) and portlandite ($Ca(OH)_2$) XRD peaks disappeared from sorted C&DW after the leaching, indicating their dissolution, which contributed to the increased pH of the solution. Neutralisation of AMD by alkaline material typically raises Ca concentrations in the treated water. However, in our study, the observed Ca increase was smaller than that reported by Gcasamba *et al.*, 2021 and Mahedi *et al.*, 2021. This difference can be attributed to the higher SO_4 concentration in the AMD used, which promoted gypsum precipitation, thereby reducing calcium leaching potential. Consequently, based on the leaching tests, borehole water was selected for further MCC experiments.

Direct aqueous mineral carbonation test

The borehole water was initially saturated with CO_2 through continuous bubbling, leading to a pH decrease to 6.0 and stabilization of CO_2 concentrations at the reactor outlet at 20 vol.% (Figure 4(a)). Upon the addition of sorted C&DW solids (Figure 4(a), Time = 0), the pH immediately increased to around 12, followed by a steady decrease to pH 7. Simultaneously, the concentration of CO_2 at the reactor outlet dropped below 10 vol.% before rising again to its initial level. Figure 4(b) shows the CO_2 uptake rate by the alkaline leaching agent (Ca-rich borehole water). The CO_2 uptake rate rose to ~400 mL/min within the first 5 min, followed by a decline and stabilisation at 50 min. These pH variations reflect both the leaching of Ca and the dissolution of CO_2 in the borehole water.

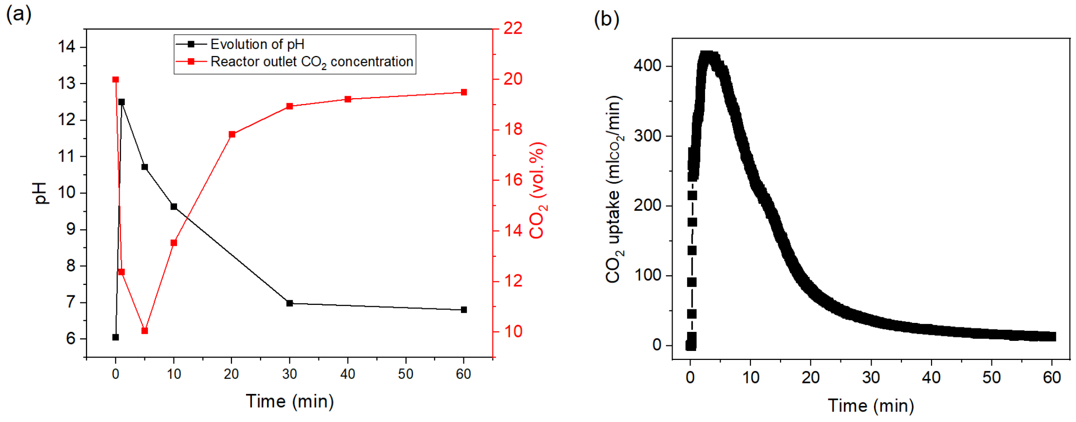

Figure 4. Direct aqueous mineral carbonation process: (a) evolution of pH and CO_2 concentration at the reactor outlet, (b) CO_2 uptake as a function of time.

The CO_2 data recorded by the online gas analyser were used in Equations 9 and 10 to determine the mass of CO_2 uptake (g-CO_2/200 g-C&DW) during the experiment.

$$Total\ CO_2\ uptake(gCO_2/200g\_C\&DW) = \frac{V_{CO2\_uptake}P}{RT} \times M_{CO2} \qquad [9]$$

where V_{CO2_uptake} (L) is the CO_2 uptake volume, P is the pressure (1 atm), R is the gas constant (0.0821 Latm/molK), T is the temperature (293 K) and M_{CO2} is the molar mass of CO_2 (44.01 g/mol). The volume of CO_2 was calculated according to Equation 10.

$$V_{CO2\_uptake} = \int_0^{t=1s} (CO_2 uptake\ rate\ at\ t - CO_2 uptake\ rate\ at\ t = 0)\, dt \qquad [10]$$

CO_2 uptake volume describes CO_2 dissolved in alkaline leaching agent and is calculated by integrating the area under the curve shown in Figure 4(b). Equation 10 was used to compute the V_{CO2_uptake} at one-second intervals. To obtain the total V_{CO2_uptake} over the entire carbonation experiment, the calculated value is multiplied by 3600 s. The volume of CO_2 absorbed during the carbonation test was 5.76 L. This volume was then used in Equation 9 to determine the mass of CO_2 uptake. The mass of CO_2 uptake was calculated to be 10.55 g-CO_2 per 200g-C&DW (i.e., 0.053g-CO_2/g-C&DW). This value is comparable with the findings reported by Ho *et al.*, (2020, 2021). Ho *et al.*, (2020) reported a total CO_2 uptake efficiency of 0.04 g-CO_2/g-concrete fines and Ho *et al.*, (2021) reported 0.13 g-CO_2/g-concrete fines under the same process conditions.

A total volume of 48 L of pure CO_2 (V_{CO2_total}) was used during the experiment to make 20 vol.% modeled CO_2 concentration at a flow rate of 0.8 L/min for 60 min. Using this data, together with the density of CO_2 (ρ_{CO2}) under ambient conditions, the mass of CO_2 feed during the carbonation experiment was determined according to Equation 11.

$$Mass\ of\ CO_2\ feed\ into\ the\ system = \frac{\rho_{CO2}}{V_{CO2\_total})} \qquad [11]$$

Then the percentage weight of CO_2 captured in the carbonation experiment can be estimated by Equation 12.

$$CO_2 captured\ (wt.\%) = \frac{Total\ CO_2\ uptake}{Mass\ of\ CO_2\ feed\ into\ the\ system} \times 100 \qquad [12]$$

A total of 95.04 g of CO_2 was fed into the system under ambient conditions, and it was estimated that 11.10 wt.% of CO_2 was captured during the carbonation experiment. After the test, carbonated C&DW was dried overnight at 105 °C and characterised using TGA. The calcium carbonate content in the carbonated C&DW increased from 18.03 wt.% to 27.09 wt.%. Based on the determined carbonate content in both the raw and carbonated C&DW, the mass of CO_2 captured in the carbonated C&DW was estimated.

The elemental composition of carbonated C&DW was found to be similar to the raw C&DW, consisting of SiO_2 (47.68%), Al_2O_3 (0.54%), Fe_2O_3 (2.16%), MnO (0.04%), MgO (0.68%), CaO (26.59%), Na_2O (0.39%), K_2O (1.21%), SO_3(0.12), LOI (19.45%), moisture content (3.17%), and volatile matter (16.28%). Although the elemental composition was similar to that of raw C&DW, further tests on specific gravity, apparent porosity, water absorption, and tensile strength are required to determine the suitability of carbonated C&DW for applications such as environmentally safe concrete paving (Llanes *et al.*, 2022).

Figure 5 shows the composition of effluent water (leaching agent) after the carbonation test compared to its composition after the initial leaching tests. By the introduction of CO_2 into the reactor, both SO_4 and Si became mobile (i.e., leached out) while Cl concentrations remained constant. Mg (79 mg/l), K (7.5 mg/l), and Na (4.9 g/l) also leached into solution, while P, Al, Cr, Fe, Mn, Pb, and Zn concentrations remained constant despite the pH changes. The introduction of CO_2 reduced the pH of the leaching agent, promoting the leaching of Si and SO_4 at pH levels below 10. Meanwhile, Ca concentrations in the leaching agent reduced from 391 mg/L to 302 mg/L, indicating that 89 mg/L of Ca precipitated as $CaCO_3$.

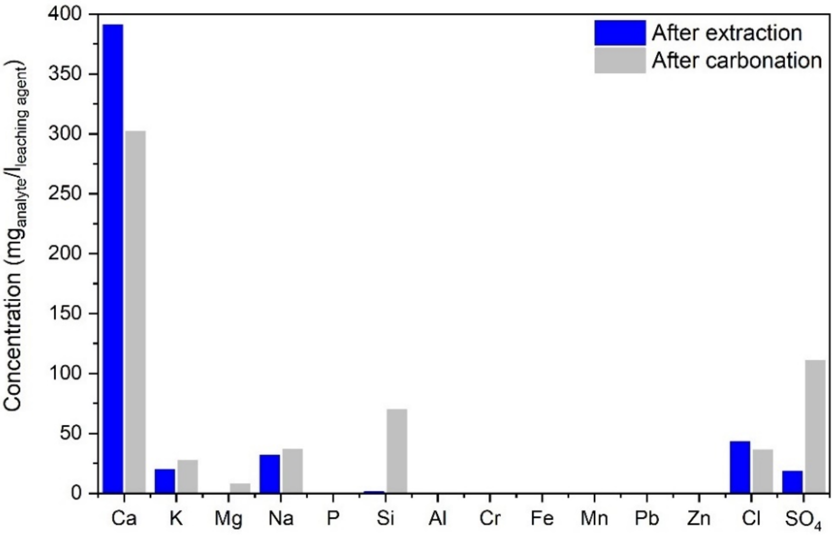

Figure 5. Composition of effluent water after carbonation test compared to the composition of leaching agent after leaching test.

Effluent water after the leaching test contained more Ca (302 mg/L) than the borehole water (63.1 mg/L) fed into the system. The effluent water showed the potential to be reused as a leaching agent, however, the concentration of SO_4 must be monitored because it reacts with Ca to form gypsum minerals.

CONCLUSION

In this study, construction and demolition waste (C&DW) was investigated as a source of calcium for direct aqueous mineral carbon capture (MCC). The XRD and XRF data showed that C&DW contained Ca suitable for CO_2 capture. The leaching tests showed that borehole water extracted 328 mg/L of Ca from the sorted C&DW compared to 85 mg/L of Ca extracted by acid mine drainage (ADM). Portlandite and ettringite minerals contained the form of Ca suitable for MCC process. The formation of gypsum mineral reduced the concentration of Ca in solution when AMD was used as a leaching agent. Sorted C&DW showed the potential to capture 0.107 g-CO_2/g-C&DW. However, the experimental work has shown that only 0.053 g-CO_2/g-C&DW was captured as $CaCO_3$. The quality of effluent water after carbonation test indicated that not all Ca reacted and precipitated in the form of $CaCO_3$. Although C&DW showed the potential to capture CO_2, its application depends on readily available C&DW. Research is ongoing to improve CO_2 capture and to look into possible applications of the by-products produced.

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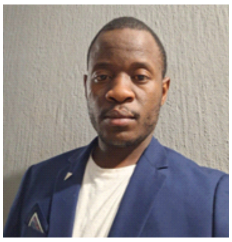

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