Active storage of captured CO_2 in net zero construction products

ASCCENT

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Report on exploratory projects

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Subject	This deliverable outlines the framework for conducting exploratory projects under Asccent project. It introduces two first rearch topics to be explored across two phases, focusing on CO_2 sequestration and carbonation processes. The document provides an overview of planned activities, selected materials, and initial testing protocols and results.
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Main authors	Viktor Kolčić, Vanja Gilja, Marijana Serdar, Ruben Snellings
Main reviewers	
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Dissemination level	

Contents

1 Introduction

The urgent need to reduce carbon dioxide (CO_2) levels in the atmosphere, one of the main causes of global climate change, has led to extensive research into sustainable mitigation strategies, particularly in sectors with high emissions intensity, such as the construction industry. This sector remains a significant contributor to the climate crisis, accounting for around 32% of global energy consumption and 34% of CO_2 emissions. The reliance on carbon-intensive materials such as cement and steel, which together account for around 18% of global emissions, further intensifies the environmental impact [1]. One of the biggest contributors is cement production, which is essential for the manufacture of concrete and emits an estimated 600 kg of CO_2 per ton of cement produced [2]. To overcome these challenges, a number of strategies have been developed to reduce CO_2 emissions. One of these strategies is the use of supplementary cementitious materials (SCMs), which help to lower the clinker content in cement and thus reduce emissions. In parallel, more advanced long-term approaches such as Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU) have emerged, which aim to either store or reuse captured CO_2 [3], [4]. One promising solution is mineral carbonation, in which CO_2 is converted into stable carbonates through reactions with materials containing calcium and magnesium [5]. Although the natural process is slow under ambient conditions, it can be significantly accelerated under controlled conditions, making it suitable for integration into industrial waste management and the development of building materials [6].

To improve the capacity of University of Zagreb Faculty of Civil Engineering and LATOM research group to develop fundamental autonomous research, exploratory projects were planned, as small spin-off projects with partners on specific topics. These projects should involve different partners from different countries depending on the individual expertise and interest of partners. The aim of these exploratory projects is to create fundamental knowledge, results and connections which have the potential to generate more international and interdisciplinary collaborative projects. In these projects, PhD researchers act as coordinators, to gain experience in project management with lower risks and administrative burden for the senior research staff. So far, two exploratory projects have been carried out as part of the ASCCENT project to assess the CO_2 sequestration potential of regional waste materials. The aim of these projects was to identify promising secondary raw materials that could serve both as CO_2 binders and as components in net-zero building products. Both projects were coordinated by Viktor Kolcic, PhD researcher employed at the University of Zagreb Faculty of Civil Engineering.

The first exploratory project carried out at UNIZG FCE focused on dry carbonation under controlled laboratory conditions. Various local waste materials were pre-treated, exposed to elevated CO_2 concentrations in a carbonation chamber and analyzed over a 28-day period to assess their CO_2 uptake. For this project, collaboration with Zavod za gradbeništvo (ZAG), Slovenia, was activated, where their proposed method was used.

The second exploratory project, conducted at KU Leuven by Viktor Kolčić as a part of the mobility programme, investigated wet carbonation combined with mechanical activation using a planetary ball mill. This approach aimed to improve reaction kinetics through simultaneous grinding and CO_2 exposure under pressure, offering insights into the potential of accelerated mineral carbonation under optimized conditions.

The results of CO_2 sequestration experiments conducted at UNIZG and KU Leuven were compared to assess the impact of different techniques and conditions on carbonation efficiency.

2 Materials

To assess the CO_2 sequestration potential of regional waste streams, seven materials were selected for testing. Although no detailed chemical composition data was available at the time of selection, materials were chosen based on their regional availability, expected quantities and indications from the literature of their potential reactivity with CO_2 - particularly materials with high calcium or magnesium content.

The collection focused on industrial and bio-based waste streams relevant to the construction and manufacturing sectors in Southeast (SE) Europe. All materials originate from facilities in Croatia and neighbouring regions. **Figure 1.** shows the geographical distribution of the collection points, while **Figure 2**. provides a visual documentation of the collection activities on site.

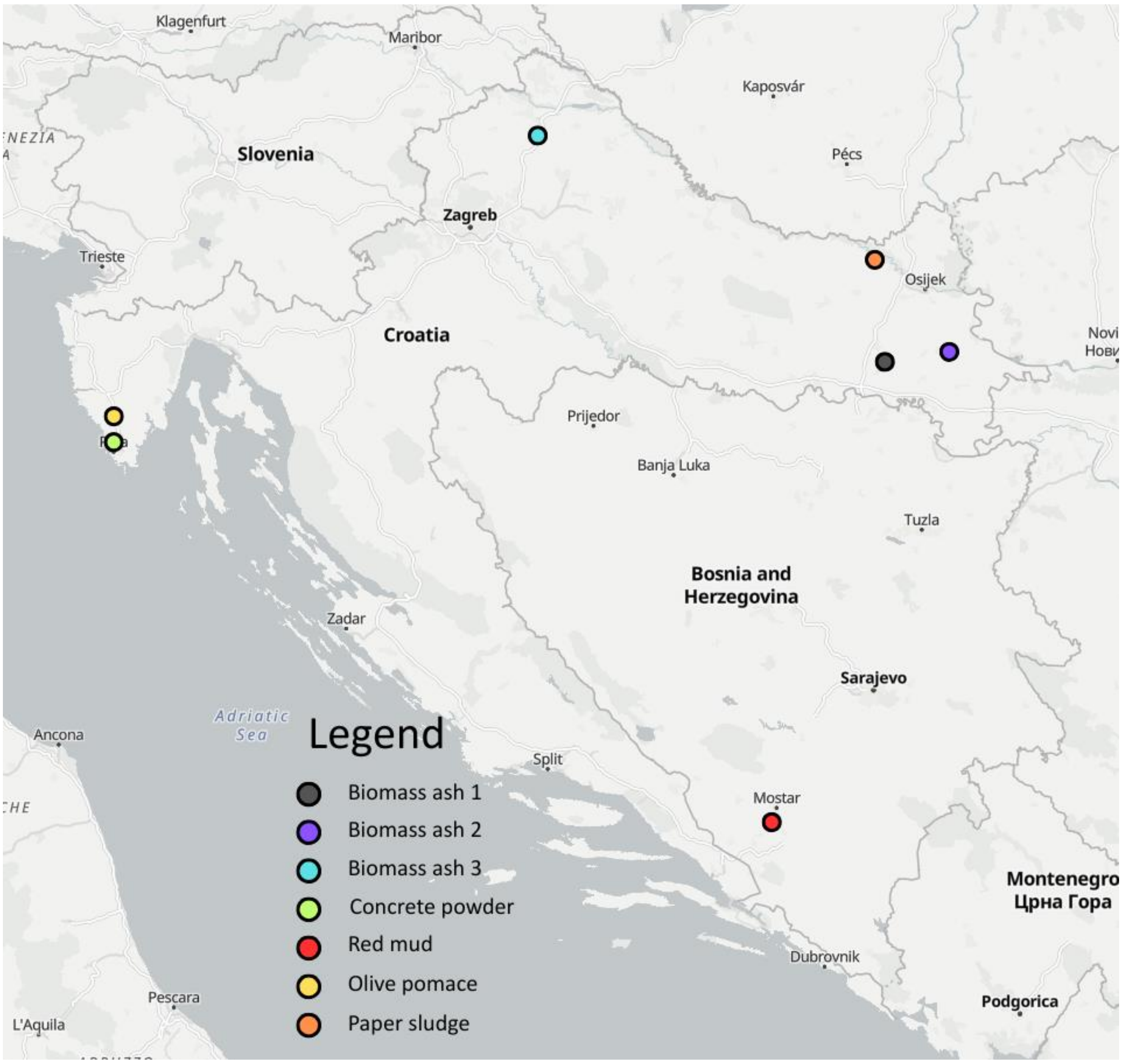


Figure 1. Map showing locations of collected waste materials used in exploratory projects

The biomass ashes (**Figure 3. a, b, c**) were obtained from bioenergy plants in Strizivojna, Vinkovci and Ljubešćica (Croatia). These ashes are by-products of bioenergy production, which are rich in calcium and therefore highly reactive with CO_2. The concrete powder (**Figure 3. d**) was provided by the company VIBROBETON - DECORGARDEN from Pula (Croatia), which specializes in concrete products. This powder comes from waste generated during the manufacturing process and is therefore a material potentially suitable for CO_2 sequestration. Red mud (**Figure 3**. **e**), a by-product of alumina production, was sourced from Dobro Selo (Bosnia and Herzegovina). This highly alkaline material offers significant potential for CO_2 sequestration due to its chemical composition. Raw olive pomace (**Figure 3**. **f**) was sourced from an oil mill in Vodnjan (Croatia). This material was first dried and then calcined in an electric furnace at 800°C with a temperature increase of 10°C per minute, resulting in olive pomace ash (**Figure 3**. **h**). Similarly, paper sludge (**Figure 3**. **g**), sourced from a packaging and paper manufacturing company DS SMITH in Belišće (Croatia), was dried and calcined under the same conditions to produce paper sludge ash (**Figure 3. i**).

Figure 2. Bioenergy plant in Strizivojna; b) Bioenergy plant in Vinkovci; c) Bioenergy plant in Ljubešćica; d) Prefabricated concrete products company in Pula; e) Red mud deposits in Dobro Selo; f) Olive pomace deposits in Vodnjan; g) Paper sludge deposits from paper production in Belišće

Figure 3. a) Biomass ash 1; b) Biomass ash 2; c) Biomass ash 3; d) Concrete powder; e) Red mud; f) Raw olive pomace; g) Raw paper sludge; h) Olive pomace ash; i) Paper sludge ash

Table 1. Summarizes sample names and their origins, providing a clear overview of the materials included in this exploratory project.

Table 1. Summary of sample names and their origins

Material	Sample ID	Origin
Biomass ash	BA1	Strizivojna, Croatia
	BA2	Vinkovci, Croatia
	BA3	Ljubešćica, Croatia
Concrete powder	CP	Pula, Croatia
Red mud	RM	Dobro Selo, Bosnia and Hercegovina
Olive pomace ash	OPA	Vodnjan, Croatia
Paper sludge ash	PSA	Belišće, Croatia

2.1 Material characterization

All materials underwent comprehensive characterization to determine their properties prior to carbonation experiments. The following analyses were performed:

- **XRF (X-ray fluorescence):** To determine the chemical composition of the materials
- **XRD (X-ray diffraction):** To identify and quantify the mineralogical phases present.
- **PSD (Particle size distribution):** To evaluate the particle size range.
- **R3 reactivity test:** To assess the chemical reactivity of the materials.

2.1.1 X-ray fluorescence

The selected materials were evaluated according to their chemical composition, in particular the presence of reactive oxides such as CaO and MgO, which are essential for effective mineral carbonation. Additionally, LOI values were used to assess the amount of volatiles, including chemically bound CO_2. XRF results for raw materials are given in **Table 2**.

Table 2. Chemical composition of materials determined by XRF analysis

Material	**ID**	**Chemical composition (%)**												
		CaO	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**P_2O_5**	**Na_2O**	**K_2O**	**TiO_2**	**MnO**	**SO_3**	**$LOI_{550°C}$**	**$LOI_{550\text{-}950°C}$**
Biomass ash	BA1	58,54	8,92	2,63	1,66	3,43	3,69	0,36	4,15	0,22	0,39	0,90	7,15	7,94
	BA2	63,46	6,16	1,30	0,77	2,13	1,27	0,00	2,63	0,11	0,24	1,25	12,65	8,02
	BA3	53,63	8,80	2,22	1,28	2,48	1,82	0,62	5,07	0,16	0,77	1,12	6,45	15,60
Concrete powder	CP	51,13	4,51	1,00	0,66	1,16	0,04	0,06	0,17	0,07	0,01	0,93	5,40	34,86
Red mud	RM	8,67	19,11	14,75	32,98	0,53	0,41	6,29	0,16	3,60	0,37	0,21	6,94	5,98
Olive pomace ash	OPA	5,02	0,05	0,23	0,68	1,88	3,23	2,58	33,71	0,02	0,00	1,13	14,03	37,43
Paper sludge ash	PSA	45,76	23,02	13,59	2,07	3,27	0,47	0,09	0,55	1,14	0,01	4,53	3,60	1,89

It is important to note that the presence of CaO, as detected by XRF, does not necessarily mean that the oxide is present in free or reactive form (e.g. as free lime). It may already be bound in stable mineral phases such as silicates, aluminates or carbonates. To accurately assess the availability of reactive CaO, further quantitative X-ray diffraction analysis (QXRD) is required to allow phase identification and quantification of the crystalline components.

All three biomass ashes had high CaO contents (54–63%), indicating strong potential for carbonation. BA2 had the highest CaO content (63.46%), while BA3 had the highest LOI950 (15.60%), indicating significant carbonate content. These ashes also contained moderate amounts of MgO (2.1–3.4%) and variable alkali content. Due to their availability and favourable chemical profiles, all three were selected for further analysis.

CP had a very high CaO content (51.13%) and a low alkali content, making it an ideal candidate for carbonation. Its exceptionally high LOI950 (34.86%) confirms a large amount of pre-existing carbonate phases (probably calcite), consistent with its cementitious origin.

Red mud exhibited a distinct chemical profile, with extremely high Fe_2O_3 (32.98%), moderate Al_2O_3 (14.75%) and relatively low CaO (8.67%). Its low LOI values indicate a limited carbonation capacity in its raw form. However, it remains of interest due to its industrial availability and potential reactivity after thermal or chemical activation.

PSA showed a balanced chemical profile with moderate CaO (45.76%), high SiO_2 and Al_2O_3 contents and a relatively low LOI. Due to its stable composition and low alkali content, it is suitable for mixing with more reactive materials.

Although OPA had a high LOI950 (37.43%), indicating a high volatile content, the levels of CaO (5.02%) and MgO (1.88%) were too low to support efficient mineral carbonation. In contrast, the combined alkali content (Na_2O + K_2O) was over 36%, raising concerns about the alkali-silica reaction when used in cementitious systems.
However, due to this exceptionally high alkali content, OPA could have potential as an alkaline activator in alkali-activated systems or geopolymers where high Na/K values are desirable. This aspect could be further explored in future studies focussing on alternative binder systems.
Due to its lack of suitability for carbonation and the risks in Portland cement systems, OPA was excluded from further analysis in this project, which focuses specifically on mineral carbonation and CO_2 sequestration.

2.1.2 X-ray diffraction

X-ray diffraction (XRD) was performed on all raw (uncarbonated) materials to identify and quantify crystalline phases. The analysis was followed by quantitative phase analysis (QPA) using rutile as an external standard. The resulting diffractograms are shown in **Figure 4-9**.

The biomass ashes (BA1, BA2, BA3) were dominated by calcium-based crystalline phases. Portlandite and lime were present in appreciable amounts, especially in BA2, which contained the highest proportion of portlandite (41.37 wt%). BA3 was rich in calcite (31.69 wt%), while BA1 had a more balanced composition with portlandite (29.53 wt%), calcite, lime and a moderate presence of hydroxyapatite and periclase. All three ashes also contained small amounts of quartz and, in the case of BA2 and BA3, traces of arcanite. The amorphous content was relatively similar, ranging from 25–28 wt%.

Concrete powder (CP) was mineralogically simpler and consisted primarily of calcite (72.04 wt%) and minor quartz, with no detectable amounts of reactive CaO-containing phases such as portlandite or lime. The amorphous content was about 27 wt.%.

Red mud (RM) had a completely different mineral profile, dominated by iron oxides, particularly hematite (19.44 wt%), goethite (9.1 wt%), and boehmite (3.19 wt%). Sodalite, magnesite, rutile and calcite were also found. The amorphous phase made up more than half of the sample (52 wt%).

Paper sludge ash (PSA) had the highest amorphous content of all samples (74 wt%). The crystalline fraction included lime (11.7 wt%), perovskite (5.16 wt%), and small amounts of quartz, anhydrite, mayenite, strontium apatite and Ni-Al. This indicates a highly disordered material structure with a broad mixture of residual crystalline components.

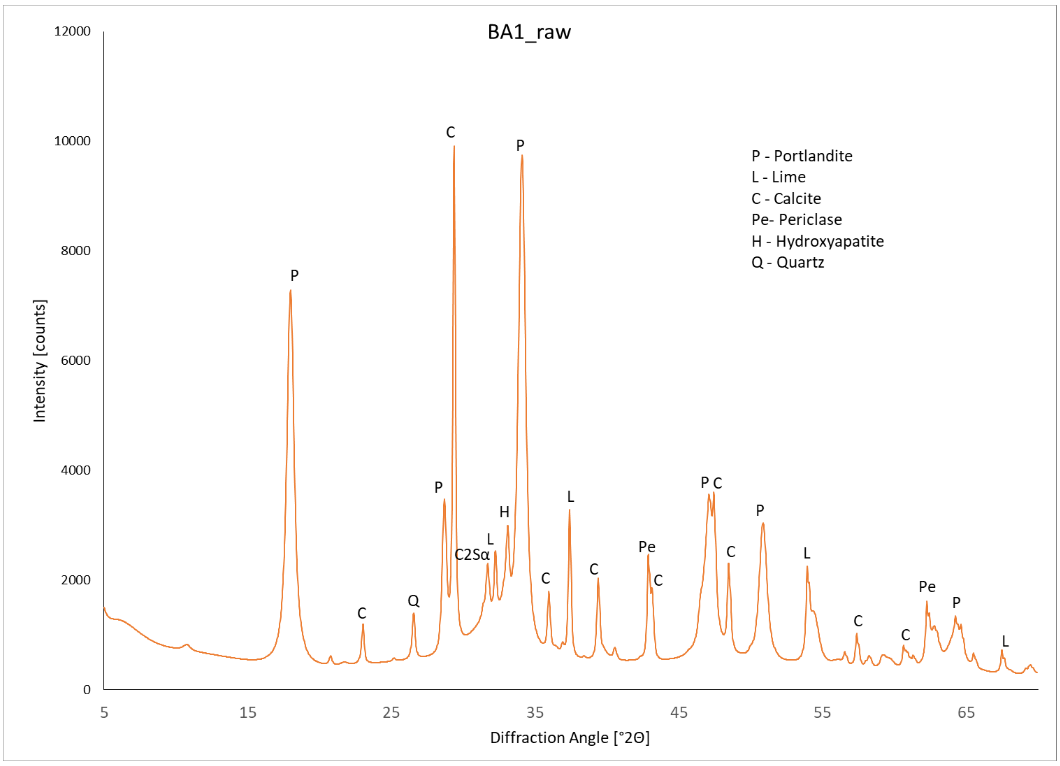


Figure 4. X-ray diffractogram of uncarbonated BA1

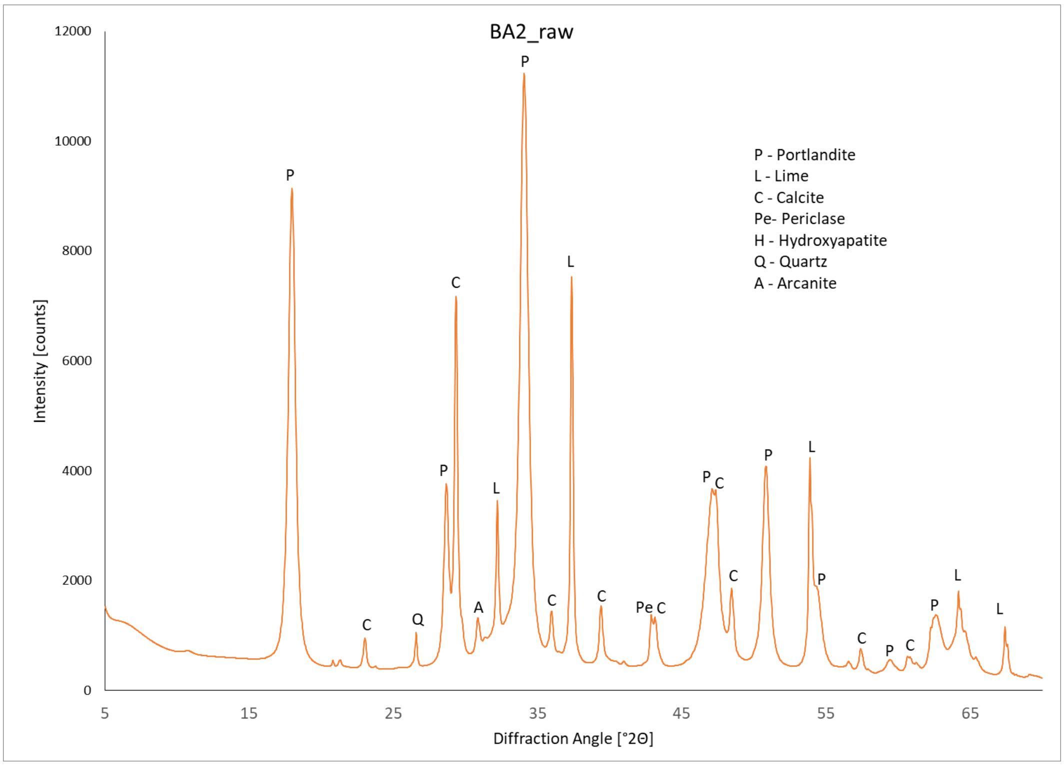


Figure 5. X-ray diffractogram of uncarbonated BA2

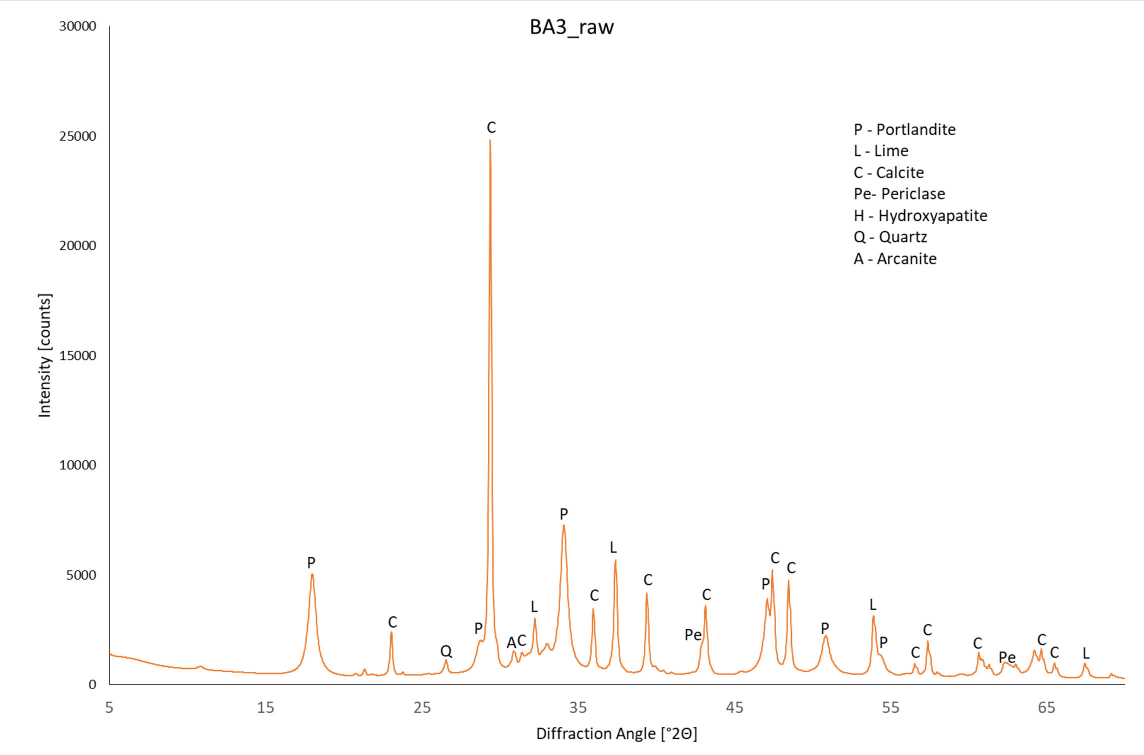


Figure 6. X-ray diffractogram of uncarbonated BA3

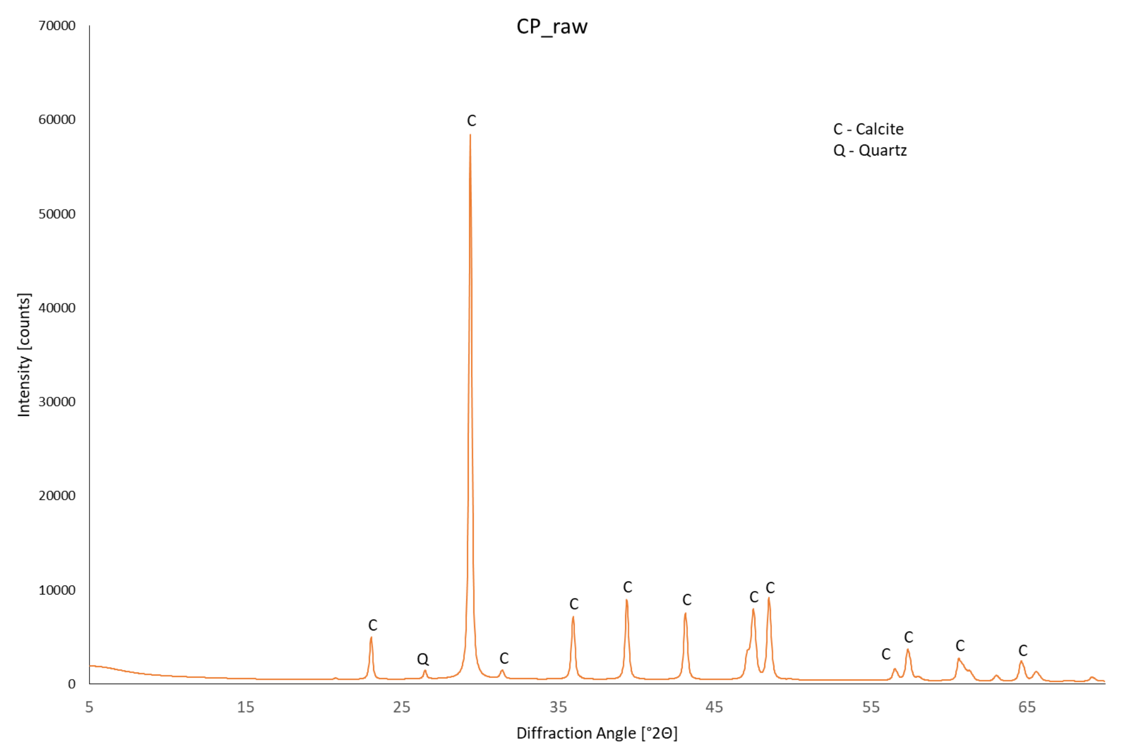


Figure 7. X-ray diffractogram of uncarbonated CP

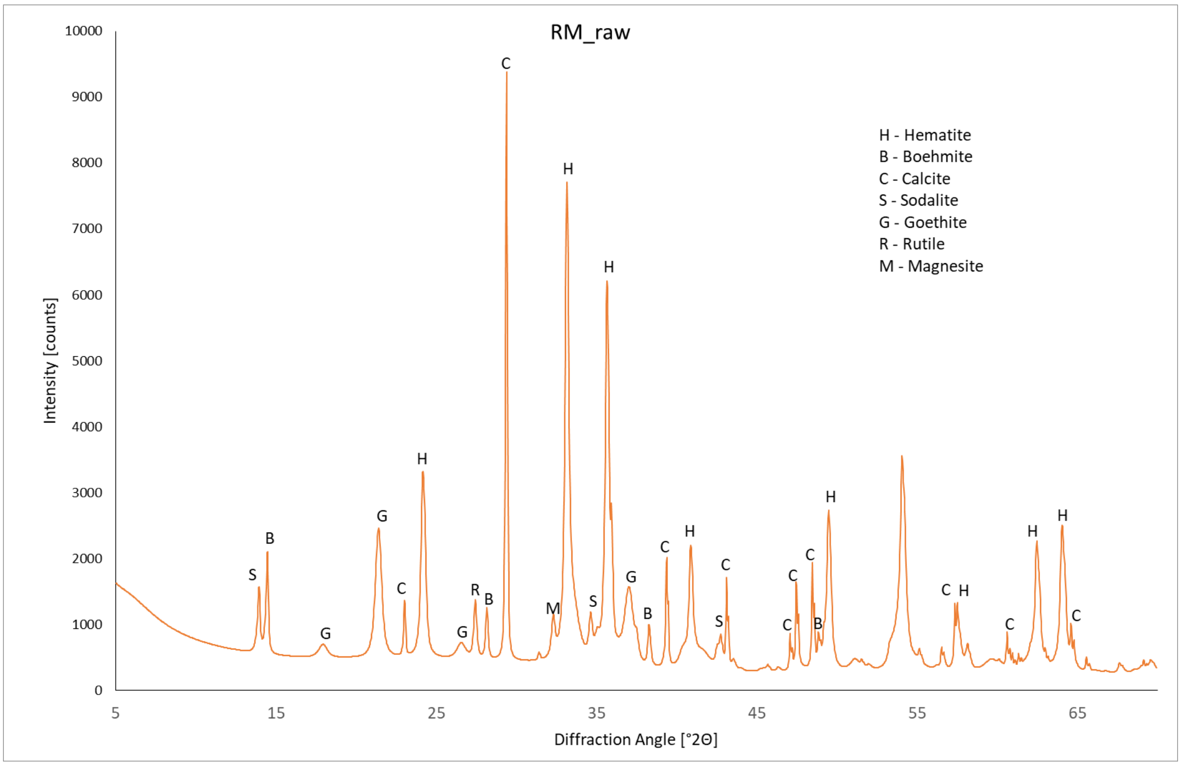


Figure 8. X-ray diffractogram of uncarbonated RM

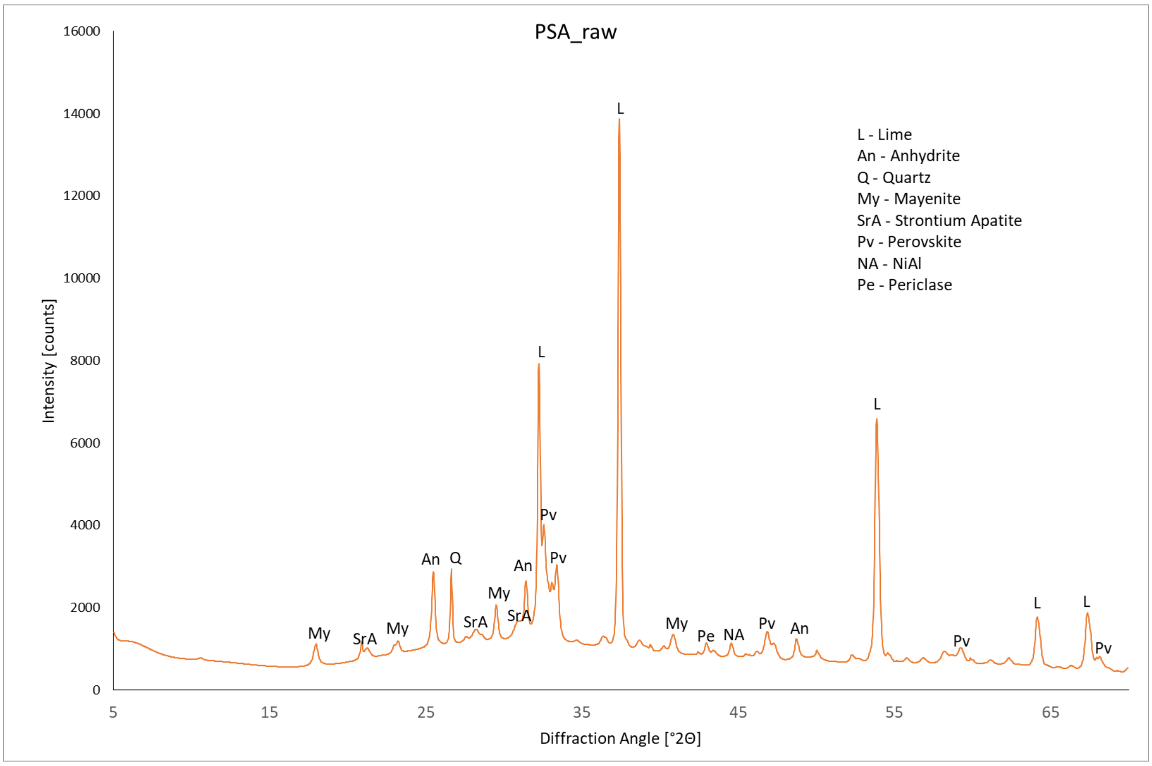


Figure 9. X-ray diffractogram of uncarbonated PSA

2.1.3 R3 reactivity test

The cumulative heat release measured by the R3 test over 7 days is presented in **Figure *10*10**. The results provide insight into the reactivity of the selected uncarbonated SCMs, simulating early-age hydration conditions.

Among the tested raw materials, PSA showed the highest reactivity, releasing over 210 J/g SCM, indicating strong pozzolanic potential. BA1 and BA3 also exhibited notable reactivity, with cumulative heat values of approximately 106 J/g SCM and 80 J/g SCM, respectively. In contrast, BA2 released only 58 J/g SCM, suggesting lower content of reactive phases. RM demonstrated moderate reactivity with a cumulative heat release of nearly 70 J/g SCM, while CP released only 19 J/g SCM, reflecting limited pozzolanic activity.

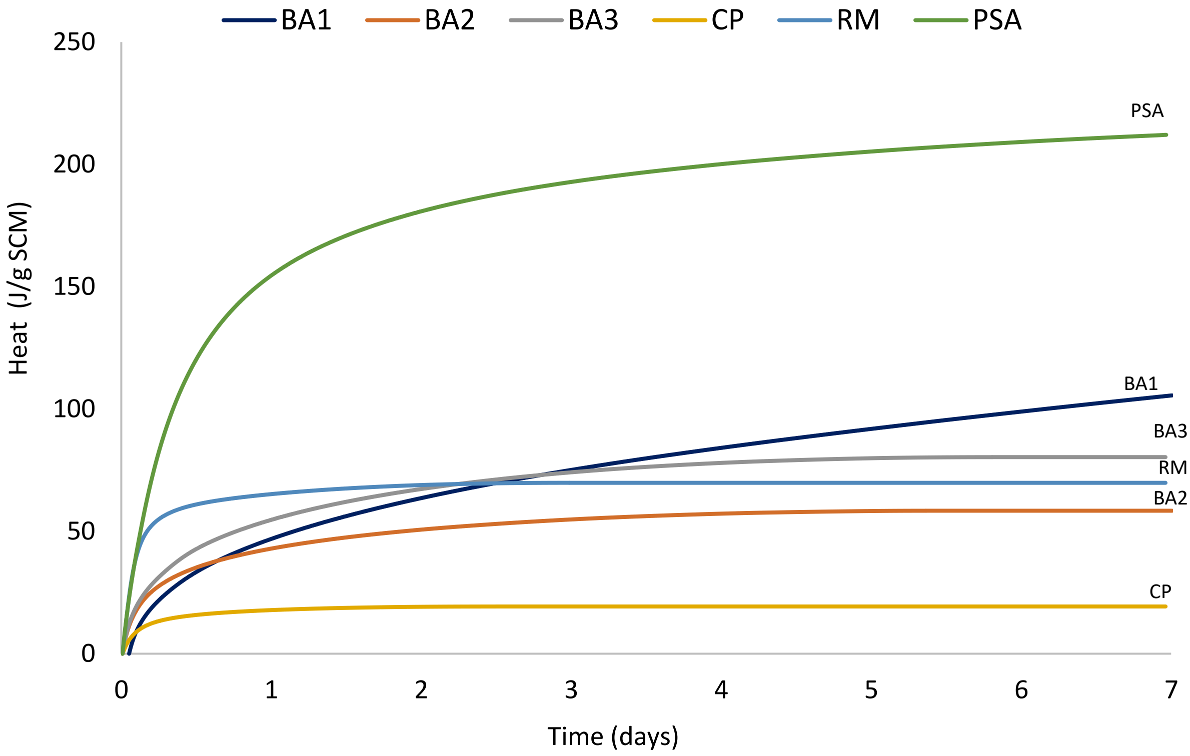


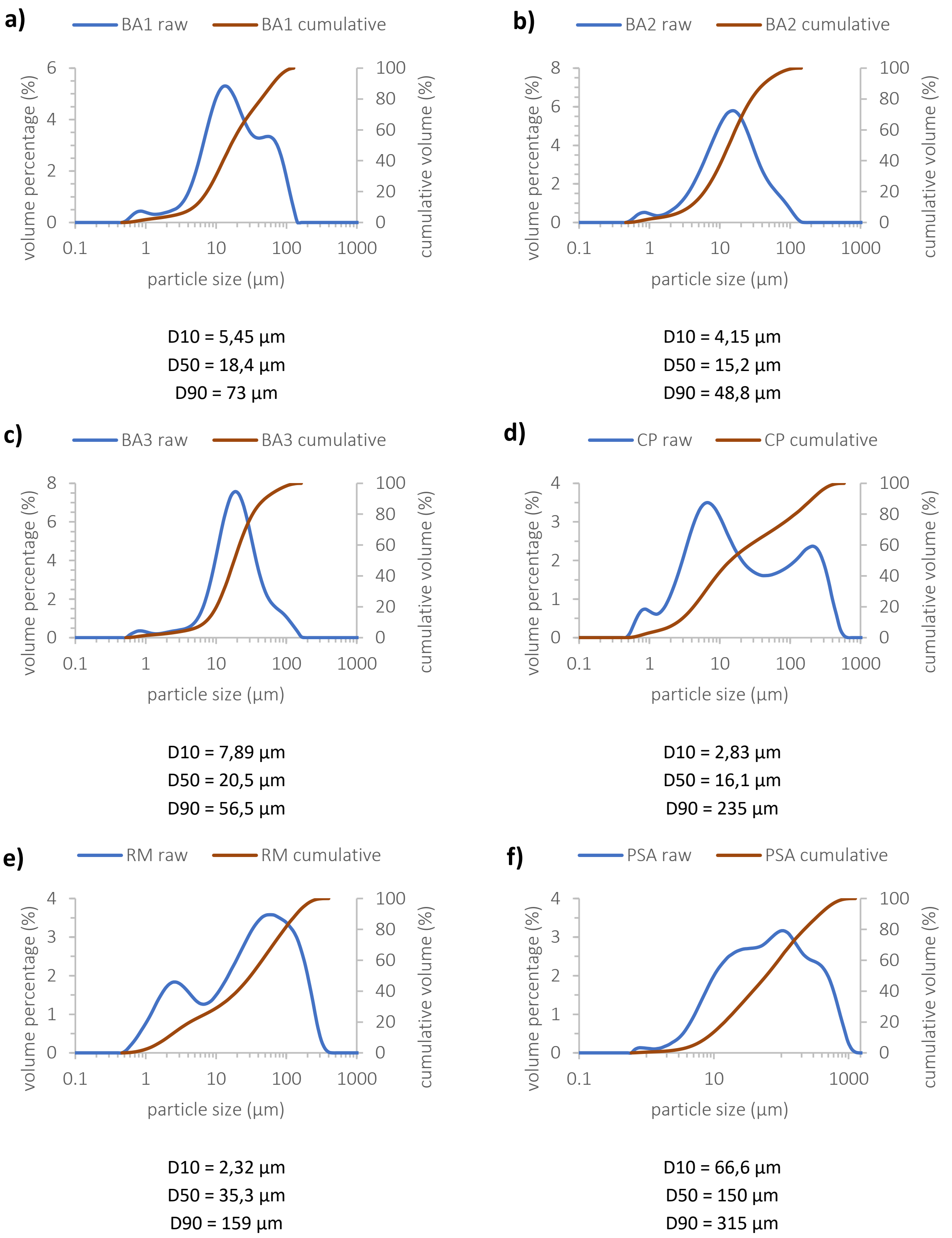
Figure 10. R3 results of raw uncarbonated materials

2.1.4 Particle size distribution

The particle size distribution of uncarbonated materials is shown in **Figure *11*11**. The analysis provides an overview of the granulometric properties of the raw samples in their untreated state.

BA1 and BA2 show similar distributions, with mean particle diameters (D50) around 15–18 µm and D90 values ranging up to around 70 µm. BA3 is slightly coarser, with D50 = 20.5 µm and D90 = 56.5 µm. These results indicate that all three biomass ashes fall within a relatively narrow fine particle size range. CP has a broad particle size distribution, ranging from D10 = 2.83 µm to D90 = 235 µm, with a median diameter of 16.1 µm. The broad distribution indicates a significant proportion of fine and coarse particles. RM shows a moderately coarse distribution, with D50 = 35.3 µm and D90 = 159 µm.

The particle size distribution is narrower than for CP, but overall the material is coarser than the biomass ash. PSA is the coarsest material among those analysed with D50 = 150 µm and D90 = 315 µm. The distribution is skewed towards larger particles, with only a small proportion in the range below 50 µm.



D10 = 5,45 µm
D50 = 18,4 µm
D90 = 73 µm

D10 = 4,15 µm
D50 = 15,2 µm
D90 = 48,8 µm

D10 = 7,89 µm
D50 = 20,5 µm
D90 = 56,5 µm

D10 = 2,83 µm
D50 = 16,1 µm
D90 = 235 µm

D10 = 2,32 µm
D50 = 35,3 µm
D90 = 159 µm

D10 = 66,6 µm
D50 = 150 µm
D90 = 315 µm

Figure 11. a) Biomass ash 1; b) Biomass ash 2; c) Biomass ash 3; d) Concrete powder; e) Red mud; f) Paper sludge ash

3 Exploratory project 1 – Dry carbonation

The first exploratory project, carried out at UNIZG FCE, focused on assessing the CO_2 uptake potential of regional waste materials through a dry carbonation process. The experimental design was based on the protocol proposed by Tominc et al. [7], ensuring methodological consistency with relevant literature. The objective was to identify promising material candidates for further investigation under standardized conditions.

3.1 Dry carbonation

The testing protocol for the first exploratory project is outlined below. It describes detailed steps undertaken to assess the CO_2 sequestration potential of regional waste streams. This includes sample preparation, carbonation treatment, and thermogravimetric analysis (TGA) for quantification of CO_2 uptake.

Material Preparation

- Sieving to ensure a particle size below 1 mm.
- Drying at 105°C for 24 hours.
- Storing in airtight containers to prevent premature carbonation during storage.

Carbonation Process

Samples are exposed in a closed carbonation chamber under controlled environmental conditions:

- CO_2 concentration: 4% (v/v).
- Temperature: 20 ± 1°C.
- Relative Humidity (RH): 80%.

Samples are distributed evenly in shallow trays as shown in **Figure *12*12**. to maximize surface exposure. The trays are placed in the carbonation chamber for a total duration of 28 days. Samples are withdrawn at predetermined intervals (e.g. 7, 14, 21, and 28 days) to evaluate carbonation progress.

Figure 12. Samples inside a carbonation chamber

Reaction Mechanisms

Under atmospheric conditions, where the CO_2 concentration is only about 0.04%, the carbonation of reactive solids is extremely slow, so that natural mineral sequestration is largely ineffective. Increased CO_2 quantities or pressures are often used to improve the reaction kinetics. One of the most reactive components of SCMs is calcium oxide (CaO), a highly alkaline compound (equation 1). However, the direct reaction between gaseous CO_2 and CaO is kinetically inhibited and proceeds only slowly. The presence of moisture accelerates this process considerably. Under such conditions, CO_2 dissolves in water, forms carbonic acid and then reacts with calcium hydroxide ($Ca(OH)_2$), which is formed by the hydration of CaO (equation 2) [6]. This sequence leads to the precipitation of calcium carbonate ($CaCO_3$), a compound with very low solubility in water (equation 3) [8].

$$\mathrm{CaO\,(s)} + \mathrm{CO_2\,(g)} \rightarrow \mathrm{CaCO_3\,(s)} \tag{1}$$

$$\mathrm{CaO\,(s)} + \mathrm{H_2O\,(g)} \rightarrow \mathrm{Ca(OH)_2\,(s)} \tag{2}$$

$$\mathrm{Ca(OH)_2\,(s)} + \mathrm{CO_2\,(g)} \rightarrow \mathrm{CaCO_3\,(s)} + \mathrm{H_2O\,(l)} \tag{3}$$

CO_2 content

TGA is used to measure the mass change in the carbonated samples as they are subjected to thermal treatment. The steps are as follows:

- The prepared sample (approximately 10 mg) is placed in a platinum pan within the TGA instrument.
- Samples are heated from room temperature to 1000°C at a rate of 10 °C/min under a nitrogen atmosphere (flow rate: 40 mL/min).

Data Analysis

- The theoretical maximum of sequestered CO_2 is determined based on the chemical composition of the samples in weight percentage (wt%), using the Steinour stoichiometric formula [9]:

$$\mathrm{CO_{2-max}\,(wt\%)} = 0.785\,(\mathrm{CaO} - 0.7\,\mathrm{SO_3}) + 1.091\,\mathrm{MgO} + 0.935\,\mathrm{K_2O} + 1.420\,\mathrm{Na_2O} \tag{4}$$

- CO_2 uptake is determined based on the CO_2 content (mass loss between 550°C and 950°C) before and after accelerated carbonation. CO_2 uptake is then calculated based on Equation (5), where CO_2 carbonated and CO_2 initial represent the CO_2 content in the dried (105 °C) material after and before carbonation.

$$CO_2 uptake(wt\%) = \frac{(CO_{2\,carbonated}(wt\%) - CO_{2\,initial}(wt\%))}{(100 - CO_{2\,carbonated}(wt\%))} \times 100 \tag{5}$$

- Carbonation efficiency (CE) is determined as the ratio between the percentage of CO_2 sequestered experimentally according to the TG analysis and the theoretical CO_2 value calculated using Steinour's equation:

$$CE\ (\%) = CO_{2-TG\ exp}\ (\%)/CO_{2-max}\ (\%) \tag{6}$$

3.2 Results

Figure 13. presents the results of CO_2 uptake and carbonation efficiency for all raw materials after 28 days of dry carbonation. The materials exhibited significant differences in their ability to bind CO_2, which can be linked to their chemical and mineralogical composition.

PSA showed the highest performance, with a CO_2 uptake of 28.6 wt% and an exceptionally high carbonation efficiency of 75.94%. This suggests a large portion of reactive CaO was successfully carbonated, despite the material's high amorphous content.
BA2 and BA3 also performed well, with uptake values of 26.62% and 14.58%, and corresponding carbonation efficiencies of 49.38% and 29.28%. BA1 showed lower uptake (13.03%) and efficiency (24.32%), despite having a high portlandite content, possibly due to differences in particle size distribution or surface reactivity.
C and red mud RM showed very limited reactivity, with CO_2 uptake below 3% and efficiencies below 10%. These results align with their mineral composition, as CP is already highly carbonated (dominated by calcite), and RM lacks sufficient reactive phases.
Overall, the results confirm dry carbonation over 28 days is most effective for materials with both a high content of reactive Calcium phases and sufficient porosity or surface area, such as PSA and BA2.

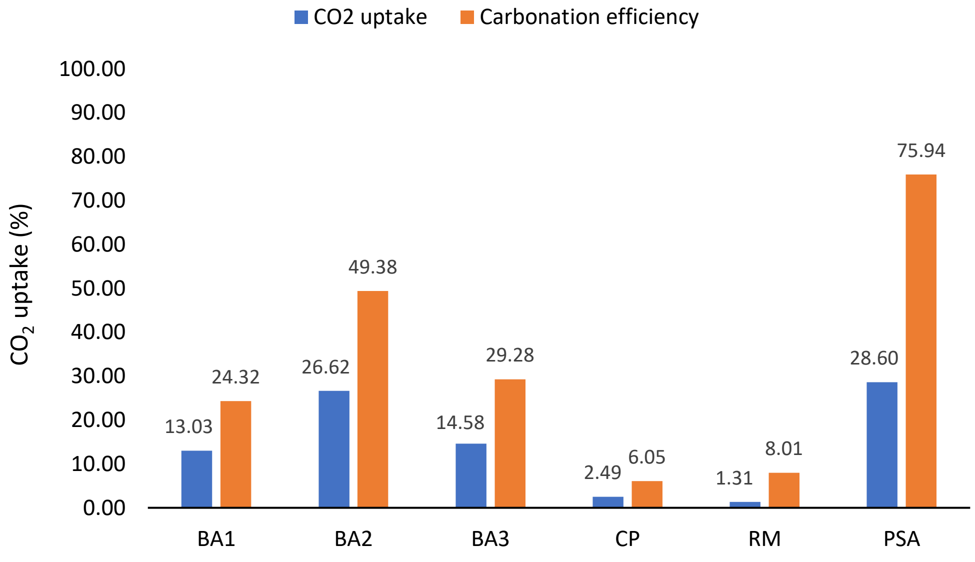


Figure 13. CO_2 uptake results following 28-day dry carbonation

4 Exploratory project 2 – Wet carbonation

The second exploratory project was conducted at KU Leuven and focused on evaluating the CO_2 uptake potential of selected regional waste materials through wet carbonation combined with mechanical activation. The protocol was developed based on the methodology proposed by De Schutter et al. [10] aiming to enhance reaction kinetics by simultaneously exposing the materials to CO_2 and intensive grinding conditions.

Material Preparation

- Sieving to ensure a particle size below 1 mm.
- Drying at 105°C for 24 hours.
- Storing in airtight containers to prevent premature carbonation during storage.

Carbonation Process

In this approach, samples were pre-dried, sieved to below 1 mm, and then subjected to wet milling in a planetary ball mill (**Figure *14*14. a**) For each test, 1 gram of material was mixed with 10 millilitres of ultrapure water and ground with 2 mm zirconia balls at a 20:1 media-to-powder ratio. The milling was performed at 500 rpm under a constant CO_2 pressure of 5 bar (**Figure *14*14. b**) for 10 minutes.

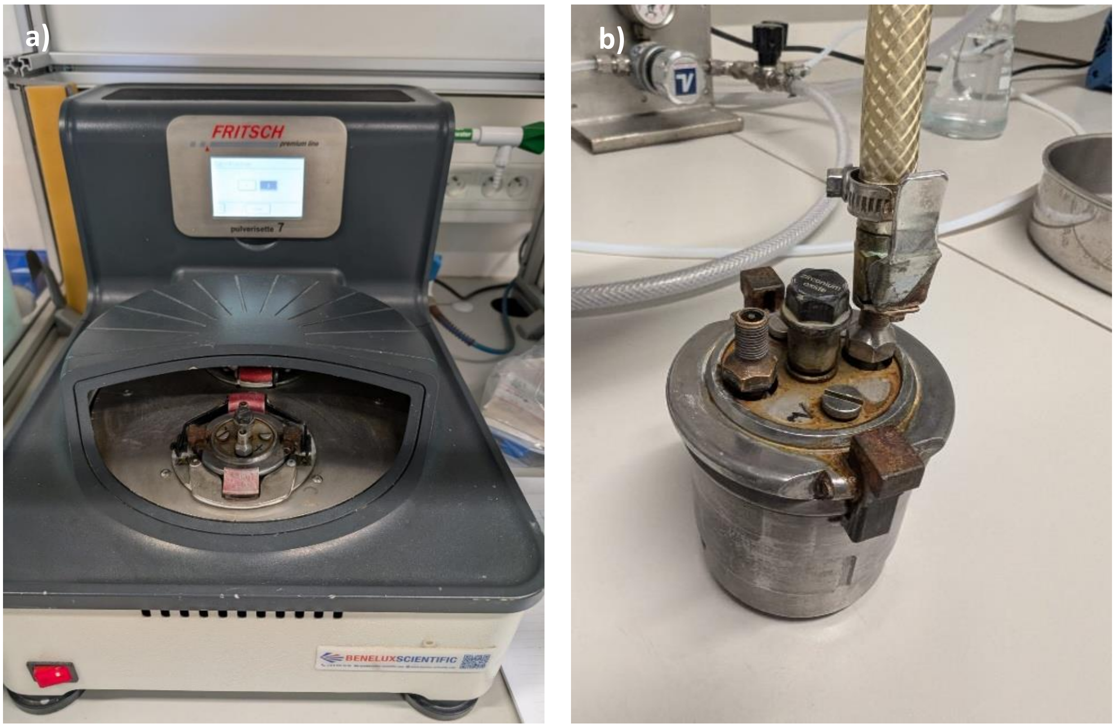


Figure 14. a) Planetary ball mill; b) Grinding jar equipped with a gassing lid for CO_2 pressurization

CO_2 content

Unlike Exploratory Project 1 (EP1), where CO_2 content was determined using TGA, in this project the measurements were carried out using a furnace-based method. Each sample was subjected to a controlled heating programme: first, the temperature was increased to 550 °C over one hour, followed by one hour of holding time. The mass was then recorded before continuing to 950 °C over the next hour, again followed by a one-hour hold. The mass loss observed between 550 °C and 950 °C was attributed to CO_2 release and used to quantify the CO_2 content. Based on this data, CO_2 uptake was calculated using the same approach as in EP1.

4.1 Results

Figure 15. presents the CO_2 uptake and carbonation efficiency of selected raw materials following 10 minutes of wet carbonation under pressurized conditions. Although the contact time was significantly shorter compared to the 28-day dry carbonation, the results show notable CO_2 binding for several materials.

BA2 achieved the highest uptake (36.97 wt%) and efficiency (68.58%), followed by BA3 and BA1, which both showed moderate to high uptake (19.50% and 20.09%, respectively) and efficiencies exceeding 35%. These values suggest that the combination of mechanical activation and CO_2 pressure can significantly accelerate carbonation reactions for Ca-rich materials.

PSA also performed well, with an uptake of 12.72% and a carbonation efficiency of 33.79%, despite its highly amorphous nature. In contrast, CP and RM showed no measurable CO_2 uptake under these conditions.

It is important to note that the CO_2 content was determined using a simplified furnace method and analytical balance. While this approach is practical for rapid screening, it may not provide the same level of precision as thermogravimetric analysis (TGA) used in EP1.

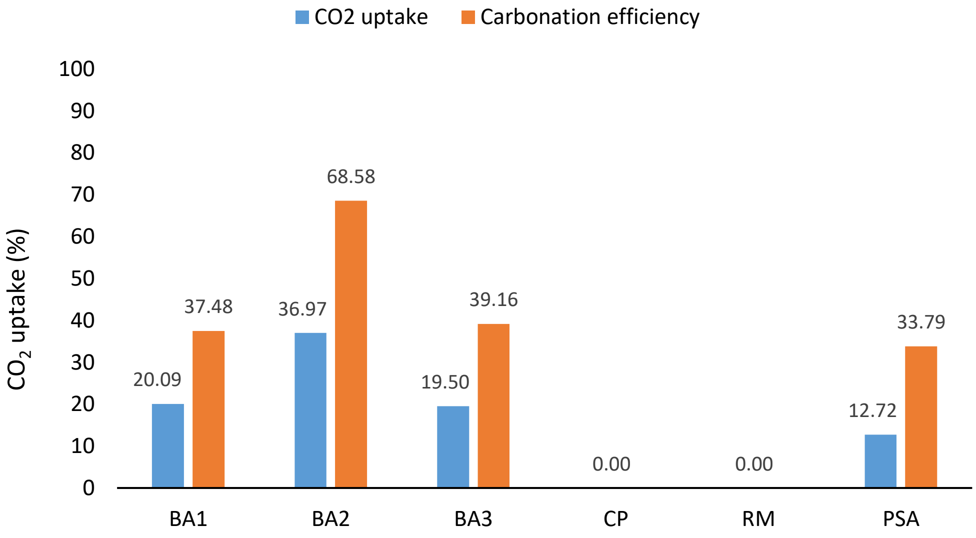


Figure 15. CO_2 uptake results following 10-minute wet carbonation

5 Conclusions

The first two exploratory projects carried out as part of the ASCCENT project provide a comprehensive initial screening of regional industrial and biomass waste for its potential to bind CO_2 through mineral carbonation processes.
A total of six different waste streams were characterized and evaluated: three biomass ashes (BA1–BA3), concrete powder (CP), red mud (RM), paper sludge ash (PSA) and olive pomace ash (OPA). Based on the chemical composition and XRD analysis, OPA was excluded from further testing due to its low CaO content and high alkali content, which are problematic for safe and efficient carbonation.

As shown in **Table 3**, both exploratory projects demonstrated that biomass ashes (especially BA2 and BA3) and paper sludge ash have significant potential for CO_2 uptake, which is supported by their high content of reactive calcium phases (portlandite, lime) and moderate amorphous fractions. These results are consistent with the reactivity tests (R3 test), the mineralogical data (XRD QPA) and the carbonation performance.

Table 3. Theoretical and experimental CO_2 uptake with corresponding carbonation efficiency for dry and wet carbonation

Sample ID	Theoretical CO_2 max uptake	Dry carbonation CO_2 uptake		Wet carbonation CO_2 uptake	
	(%)	(%)	Carbonation efficiency (%)	(%)	Carbonation efficiency (%)
BA1	53.59	13.03	24.32	20.09	37.48
BA2	53.91	26.62	49.38	36.97	68.58
BA3	49.80	14.58	29.28	19.50	39.16
CP	41.14	2.49	6.05	0	/
RM	16.36	1.31	8.01	0	/
PSA	37.65	28.60	75.94	12.72	33.79

In Exploratory Project 1, where dry carbonation was carried out over 28 days, PSA achieved the highest CO_2 uptake (28.6 wt%) and carbonation efficiency (75.94%). BA2 also performed well, while CP and RM showed only low reactivity, which is consistent with their mineral composition and pre-existing carbonation.

In contrast, Exploratory Project 2, wet carbonation with mechanical activation under pressure was carried out and considerable CO_2 binding was achieved in just 10 minutes. Although the CO_2 content was measured using a simplified furnace method (less accurate than TGA), the results still confirmed the effectiveness of accelerated wet carbonation for Ca-rich samples, with BA2 again achieving the highest uptake (36.97 wt%).

The comparison of the two methods clearly shows that the mechanical activation and the increased CO_2 pressure significantly improve the reaction kinetics and shorten the treatment time. However, the dry carbonation approach offers a more scalable and passive solution with the possibility of integration into curing processes for low-carbon building materials.

In conclusion, PSA and BA2 have proven to be the most promising materials for further development, while the established protocols and testing framework provide a solid foundation for future research projects within ASCCENT.

6 Literature

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