CO_2 capture using sodium silicates prepared with construction and demolition waste

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Introduction

The increase in greenhouse gas emissions constitutes one of the most important environmental issues today. Among them, carbon dioxide (CO_2), primarily generated by anthropogenic activities, has increased its atmospheric concentration, reaching historic levels in 2023, with a global surface average of 420 parts per million (ppm) (WMO, 2024). In this context, carbon capture, utilisation and storage (CCUS) technologies have emerged as a solution to reduce CO_2 emissions and contribute to net CO_2 removal from the atmosphere (Hanson et al., 2024). The performance of CCUS technologies largely depends on the properties of the CO_2 sorbent material, which must exhibit high CO_2 capture capacity under various process conditions, good kinetics, and low-cost regeneration capability (Dziejarski et al., 2023).

At a global level, construction and demolition waste (CDW) is estimated at approximately 11,000 Mt/year, and its volume continues to increase due to urban expansion and infrastructure development. Despite nearly 75% of CDW exhibiting high potential for valorization, a significant fraction is still disposed of in landfills (Purchase et al., 2022). This situation has driven interest in their use as raw materials for the synthesis of value-added materials, specifically CO_2 sorbents, such as alkaline silicates, particularly lithium silicates, which have shown promising results in CO_2 capture applications (Hernández-Palomares et al., 2023). Within a circular economy framework, there is growing interest in exploring the use of CDW as a raw material for the synthesis of sodium silicates as an alternative to lithium silicates, considering the greater abundance and availability of sodium, and given that its utilization from this type of waste has been scarcely investigated in the context of CO_2 capture.

Material and methods

Sodium silicates were prepared using the wet mixing method, employing construction and demolition waste and sodium hydroxide (NaOH). In the material from waste, the sodium content was varied to evaluate its effect on phase formation. In the first sample (NaSi-ES), the sodium content was adjusted based solely on the formation of sodium orthosilicate as the main phase. In the second sample (NaSi-ET), given the formation of secondary phases associated with the CDW composition, it was ensured that sodium orthosilicate formation was not compromised. Finally, in the third sample (NaSi +20% Na), based on stoichiometry, considering the formation of secondary phases, a 20% excess of sodium was added. For comparison purposes, an additional silicate was prepared using sodium metasilicate (Na_2SiO_3) and NaOH (NaSi-AG). The sodium silicates were characterized by X-ray diffraction (XRD) and N_2 adsorption-desorption. Subsequently, the CO_2 capture behaviour of all materials was evaluated by thermogravimetric analysis (TG), using CO_2 of 15 and 20 vol% at high temperatures.

Results and discussion

The formation of sodium orthosilicate phases (Na_4SiO_4) was corroborated by XRD analysis (Figure 1). In the samples prepared from CDW, Na_4SiO_4 was identified, along with secondary phases, indicating the heterogeneous composition of the CDW. In contrast, in the sample prepared from analytical-grade reagents, the formation of Na_4SiO_4, sodium pyrosilicate ($Na_6Si_2O_7$), and sodium carbonate (Na_2CO_3) was observed.

CO_2 capture as a function of increasing temperature for samples prepared from CDW (Figure 2) was evaluated at different CO_2 concentrations. Under a 20 vol% CO_2 atmosphere, the NaSi-ET and NaSi-ES samples exhibited similar behavior, reaching maximum weight gains of 10.9 and 10.7%, respectively, at 750 °C, corresponding to CO_2 capture capacities of 109 and 107 $mg_{CO2}/g_{material}$. In contrast, the NaSi +20%Na sample showed a significantly higher weight gain, reaching a maximum value of 14.5% at 800 °C, equivalent to 145 $mg_{CO2}/g_{material}$. NaSi-ET and NaSi +20%Na were selected to evaluate the effect of CO_2 concentration. When the CO_2 concentration was reduced to 15 vol%, the NaSi-ET sample reached a maximum weight gain of 8.9% at 700 °C, corresponding to 89 $mg_{CO2}/g_{material}$. Meanwhile, the NaSi +20%Na sample maintained its capture capacity, reaching a weight gain of 14.3% at 800 °C. Notably, unlike the other samples, the decrease in CO_2 concentration did not significantly affect the sample's capture capacity, suggesting greater efficiency of this material against variations in CO_2 partial pressure.

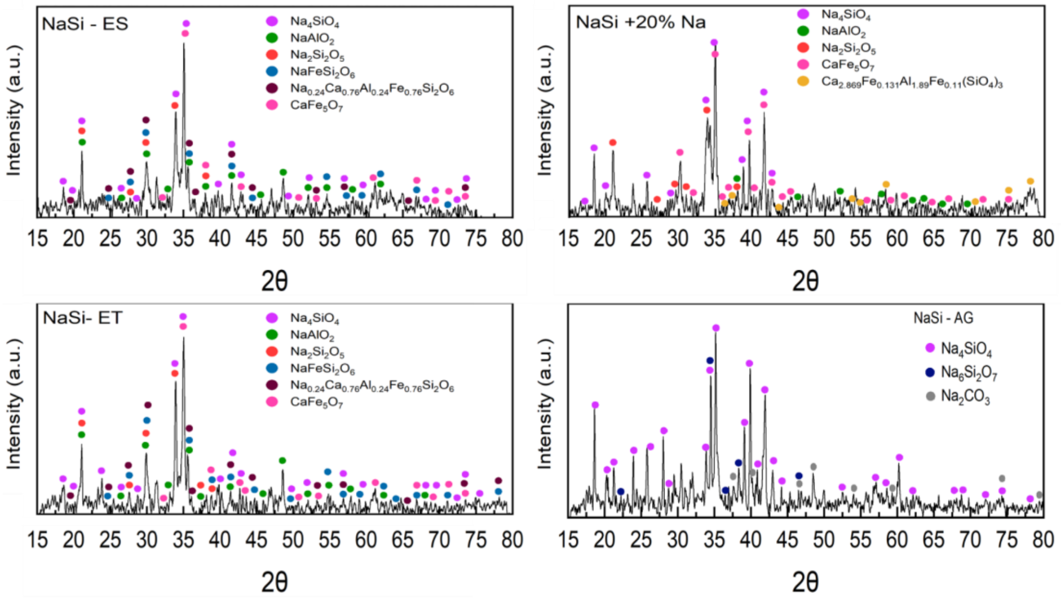

Figure 1. XRD patterns of the sodium silicates prepared with CDW and analytical grade reagents.

Additionally, the sample prepared with analytical-grade reagents exhibited a maximum CO_2 capture of 13.4% at 20 vol% CO_2, corresponding to 134 $mg_{CO2}/g_{material}$, a value lower than that obtained for the NaSi +20%Na sample.

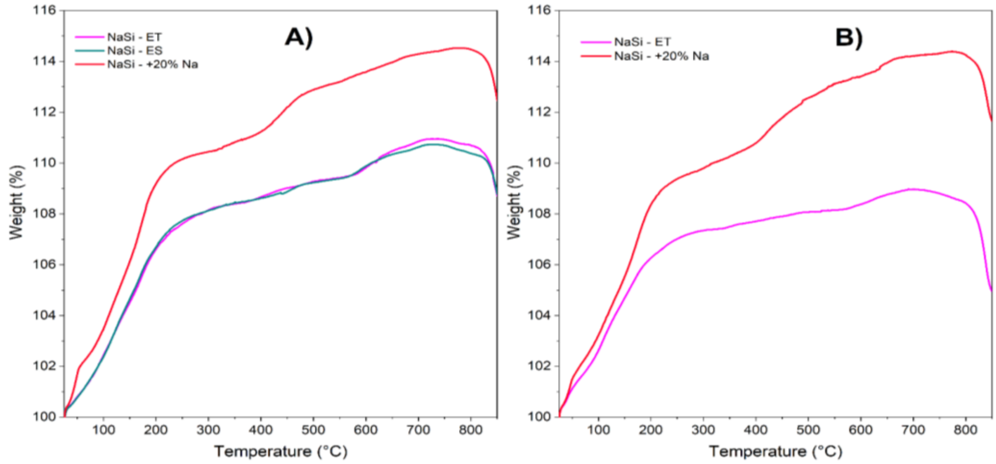

Figure 2. Dynamic thermograms of sodium silicates prepared from CDW under: A) 20 vol.% and B) 15 vol.%.

Conclusions

Construction and demolition waste was successfully used as a precursor for the synthesis of sodium silicate. According to the results, the sample prepared with excess sodium showed the highest CO_2 capture capacity, surpassing the analytical-grade material, reaching up to 145 $mg_{CO2}/g_{material}$ at 800 °C, with its performance unaffected by decreasing CO_2 concentration.

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