Physico-chemical changes in alkali activated slag under accelerated carbonation

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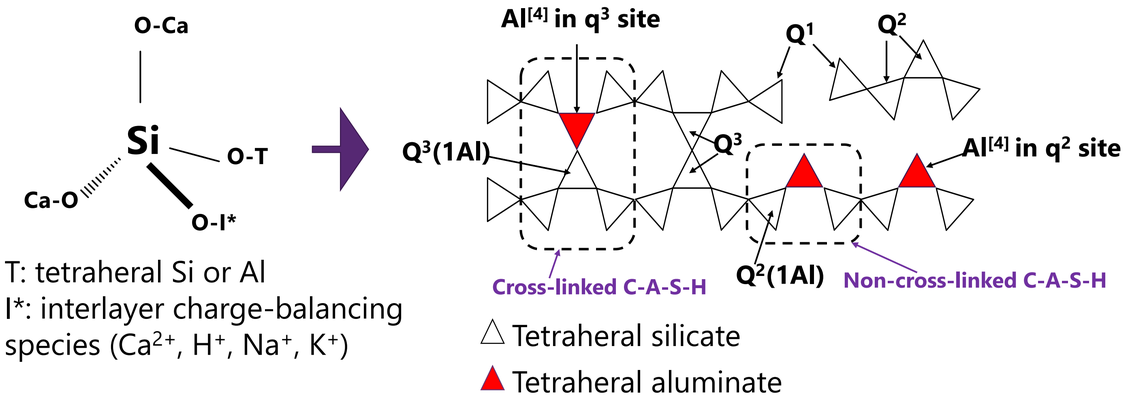
Introduction

- **Alkali activated slag (AAS)** is an amorphous alkali-aluminosilicate gel produced from blast furnace slag (BFS) and alkaline solution as an activator. With a good physico-chemical performance and potential in immobilizing waste, AAS is promising as an alternative for the Ordinary Portland Cement (OPC) in nuclear related applications.



T: tetraheral Si or Al
I*: interlayer charge-balancing species (Ca^{2+}, H^+, Na^+, K^+)

△ Tetraheral silicate
▲ Tetraheral aluminate

- **Carbonation** is one of the crucial durability issues of reinforced OPC (i.e. corrosion of reinforcing steel bars). AAS is also expected to be degraded when exposed to CO_2, though the understanding the effect of carbonation on AAS remains limited. In general, the process could be proposed as follow:

$$CO_{2\,(g)} \rightarrow CO_{2\,(aq)} + H_2O \rightarrow H_2CO_3 \rightarrow CO_3^{2-} + 2H^+$$

$$CO_3^{2-} + 2NaOH \rightarrow Na_2CO_3 + 2OH^-$$

$$Na_2CO_3 + Ca^{2+} + 2OH^- \rightarrow CaCO_{3\,(s)} + 2NaOH$$

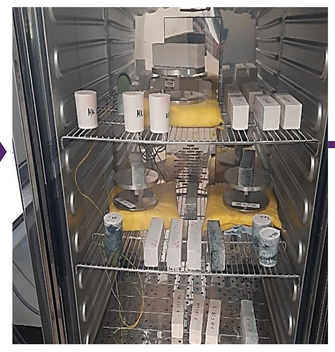
Objectives

Investigate changes in mineralogy, chemistry and microstructure of AAS subjected to carbonation → Understand the mechanism of AAS's carbonation

Develop models to predict the (long-term) performance of AAS upon carbonation

Methodology

1% CO_2, 20℃, 60% RH



- 7
- 14
- 28 days

- **Mechanical strength**
- **Carbonation depth**
- **Mineraology analysis: NMR, TGA,** XRD, FTIR
- **Microstructure analysis: SEM,** BET, MIP

Results & Discussion

Microstructure and related physical properties

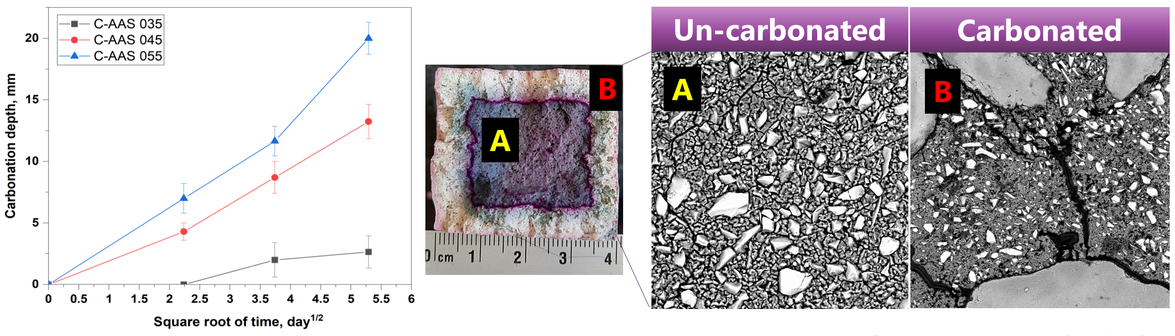


Fig 1. Carbonation depth of AAS with various water/binder (WB) after 7, 14, 28-day carbonation

Fig 2. SEM image of AAS with 0.35 of WB after 28-day carbonation

Carbonation depth of AAS increased over time of exposure and nearly followed SQRT (t) law as observed for OPC.

The structure of AAS became more cracking due to dissolution/precipitation of solid phases during carbonation.

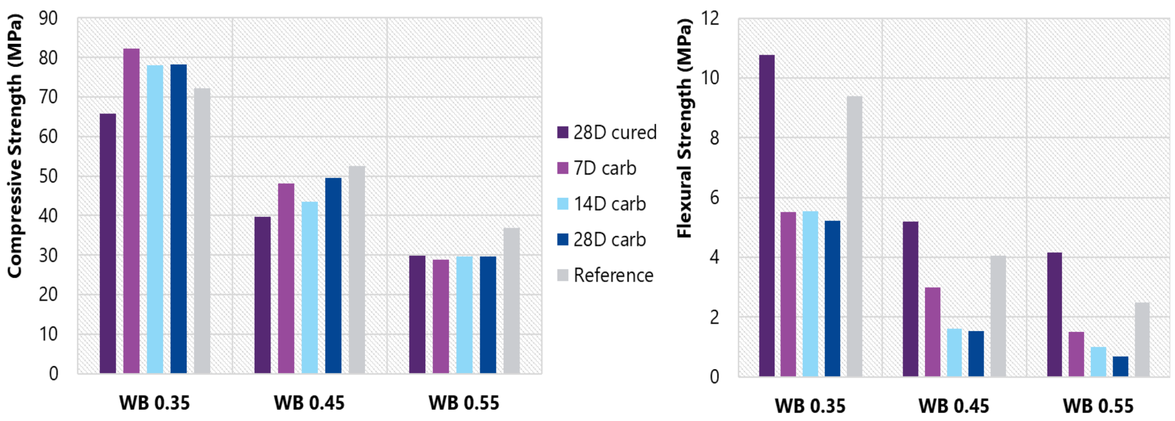


Fig 3. Mechanical strength of AAS with 0.35, 0.45, 0.55 of water/binder (WB) after 7, 14, 28-day carbonation compared with 28-day cured and reference sample

Compressive strength was not affected much by carbonation due to the compensation between the weakening caused by cracks and the strengthening from carbonate products.

Flexural strength decreased significantly upon carbonation, especially at AAS with high WB, because of considerable influence of cracks.

Chemical properties

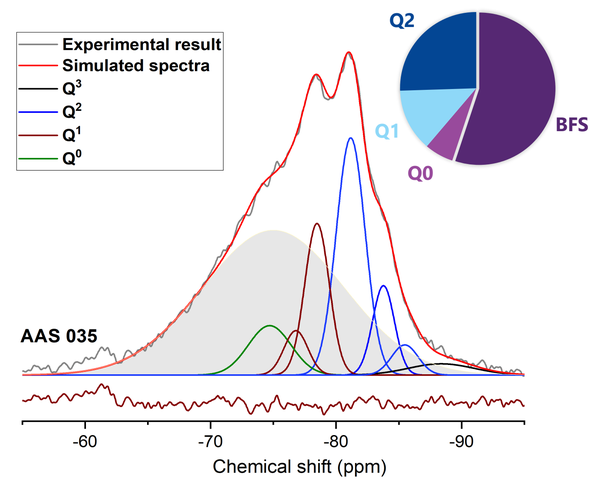


Fig 4. Deconvoluted ^{29}Si NMR spectra of uncarbonated AAS with 0.35 of WB

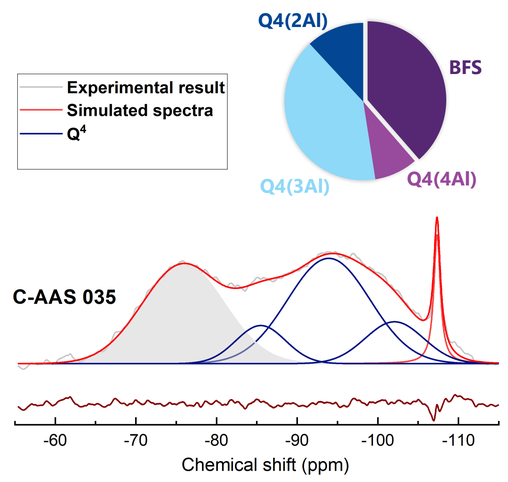


Fig 5. Deconvoluted ^{29}Si NMR spectra of carbonated AAS with 0.35 of WB

Low cross-linked Si sites in C-A-S-H gels: Q^0, Q^1, Q^2 → CO_2 → Very high cross-linked Si sites in C-A-S-H gels: Q^4

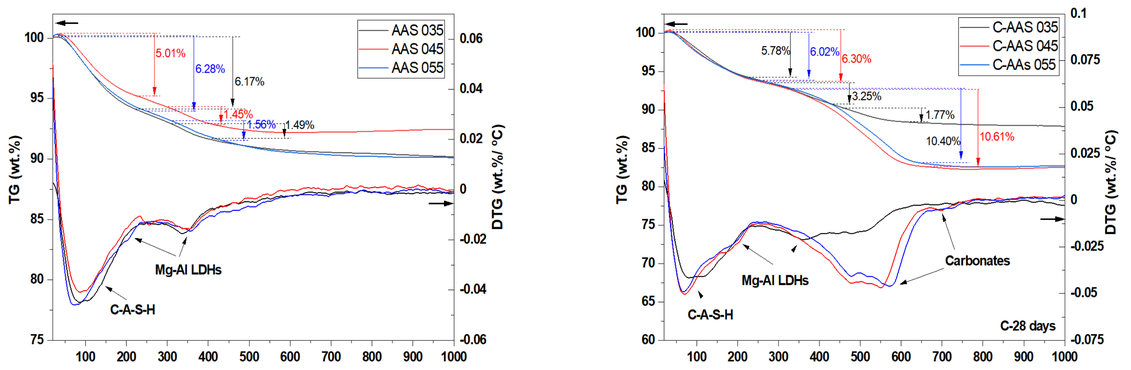


Fig 6. TG & DTG spectra of uncarbonated (AAS) and carbonated (C-AAS) samples with various WB

Upon carbonation, the thermal stability of AAS decreased, and carbonates were formed. The higher water/binder used, the more carbonates detected.

Conclusion & Outlook

AAS is relatively **vulnerable to carbonation** at 1% CO_2, 20℃, and 60% relative humidity

1) In contrast to OPC, the flexural strength of AAS decreased significantly, while the compressive strength was not much influenced by the carbonation. The microstructure of carbonated AAS is **more cracking**.
2) The C-A-S-H gel became **more cross-liked** after carbonation with the predominant **Q^4** sites instead of **Q^1 and Q^2** in uncarbonated AAS.

Outlook:

Develop geochemical/conceptual models to better understand the AAS's carbonation

This work has partially received funding from the European Union's Horizon 2020 research and innovation programme for Nuclear Fission and Radiation Protection Research (Call NFRP-2019-2020) under grant agreement No. 945098 (PREDIS).

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