# Durability of calcium sulfoaluminate cement concrete

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# Introduction

- Calcium sulfoaluminate cement (CSAC), first developed in China in the 1970s, has received significant attention because of its expansive (or shrinkage-compensating) and rapid-hardening characteristics, low energy-intensity and low carbon emissions.
- Most research on CSAC has focused on the production and hydration of the cement, while in this paper the focus is on the durability issues of CSAC concrete, where there is a lack of consensus among the researchers.
- The durability issues of several aspects including the pore structure and general transport properties, shrinkage and cracking potential, freeze-thaw damage, sulfate attack, alkali-silica reaction, carbonation and steel corrosion are discussed.
- Based on the mixed findings, we concluded some possible ways of the orientations of the future studies on the durability of CSAC.

# Steel corrosion

**Table 1. Summary of literature on steel corrosion in CSAC concrete**

| CSAC composition | Experimental conditions | Results | Ref. |
|---|---|---|---|
| CSA(1)-$C_2S$: 27% $C_4A_3\$$, 40% $C_2S$, 11% C\$, 3% $C\$H_{0.5}$;<br>CSA(2)-PC: 30% CSA (37% $C_4A_3\$$, 6% $C_2S$, 22%C\$, 3% $C\$H_{0.5}$) + 70% PC | Reinforced concrete specimens: *w/c*=0.35, cement content 530 kg/m³; 280 ×115× 150 mm prisms consisting of two layers of black steel. Preconditioning: Cured at 100% RH for 14 d, followed by exposure to lab air for 14 d; A plastic dam was placed on the top and all other surfaces were coated with a two-part waterproof epoxy. Accelerated corrosion (ASTM G109): The dammed area was subjected to repeated 4-week cycles consisting of 2-week ponding in 30 g/L NaCl solution and 2-week drying. PC concrete (*w/c*=0.4, cement content 450 kg/m³) was prepared as reference; the 28 d compressive strengths of the CSA(1)-$C_2S$, CSA(2)-PC and PC concretes were 67, 56 and 56 MPa, respectively. | The CSA(1)-$C_2S$ system started to show severe corrosion after 2 cycles, and stabilized after 4 cycles. The other systems showed low or intermediate corrosion after 30 cycles. LPR data matched the corrosion. The CSA(1)-$C_2S$ system half-cell potential was >5 times more negative than that of the other two systems, while the corrosion current density was 3 times higher. | (Moffatt and Thomas, 2018) |
| CSA(1)-$C_2S$: 27% $C_4A_3\$$, 40% $C_2S$, 11% C\$, 3% $C\$H_{0.5}$;<br>CSA(2)-PC: 30% CSA (37% $C_4A_3\$$, 6% $C_2S$, 22%C\$, 3% $C\$H_{0.5}$) + 70% PC | Reinforced concrete specimens: *w/c*=0.55, cement content 327 kg/m³, 150×150× 530 mm prisms with two rebars (11.3 mm diameter) – a standard carbon steel bar placed 50 mm below the top surface and a 316 stainless bar above the bottom surface. Preconditioning: Cured in wet burlap for 24 h, then demolded and placed under wet burlap for 28 d. Exposure: marine environment at the high tide level. Evaluations: linear polarization with three-electrode cell; cored specimens for slice-by-slice (1 mm) chloride content analysis. PC concrete (*w/c*=0.4, cement content 450 kg/m³) was prepared as reference. | After 3 years, the CSA(1)-$C_2S$ system had the lowest surface chloride concentration of 0.18%, but the highest chloride concentration of 0.11% at the position of the rebar (threshold=0.05%). The other systems showed far greater surface concentrations (0.5%-0.7%), but the threshold concentration penetrated only 20-30 mm. The steel was corroded more severely in the CSA(1)-$C_2S$ system. | (Moffatt and Thomas, 2018) |
| A commercial CSAC produced in Italy, with 78% CSA clinker (52% $C_4A_3\$$, 20% $C_2S$ and minor phases) and 22% anhydrate. | Reinforced concrete specimens: *w/c*=0.35, cement content 530 kg/m, 70 mm diameter×110 mm cylinders with ribbed steel bar (16 mm diameter, sand blasted). Preconditioning: moist cured for 7 d. Exposure conditions: cycles at 20 ℃ or 40 ℃, 80% or 95% RH, and 48 h water immersion; a series of specimens were put in the cycles after accelerated carbonation (4% $CO_2$, 65% RH). PC and limestone PC concrete specimens were prepared with the same mix proportions. | The steel was initially passive in the CSAC concrete; CSAC tented to have a higher carbonation rate than the references, but a lower corrosion rate than limestone PC concrete (higher than PC concrete). Blending PC into CSAC can help improve its resistance to carbonation and corrosion. | (Carsana, et al., 2018) |
| A commercial CSAC from China. | Centrifuge cast fine aggregate steel reinforced concrete (*w/c* = ~0.25) pipe made in 1978, put in service (tidal zone, twice daily immersion by sea water) for 14 years. No comparison with PC. | The steel mesh from the section close to low tide with a 7-8 mm concrete cover was uncorroded after 14 years. | (Zhang and Glasser, 2005) |

# Steel corrosion

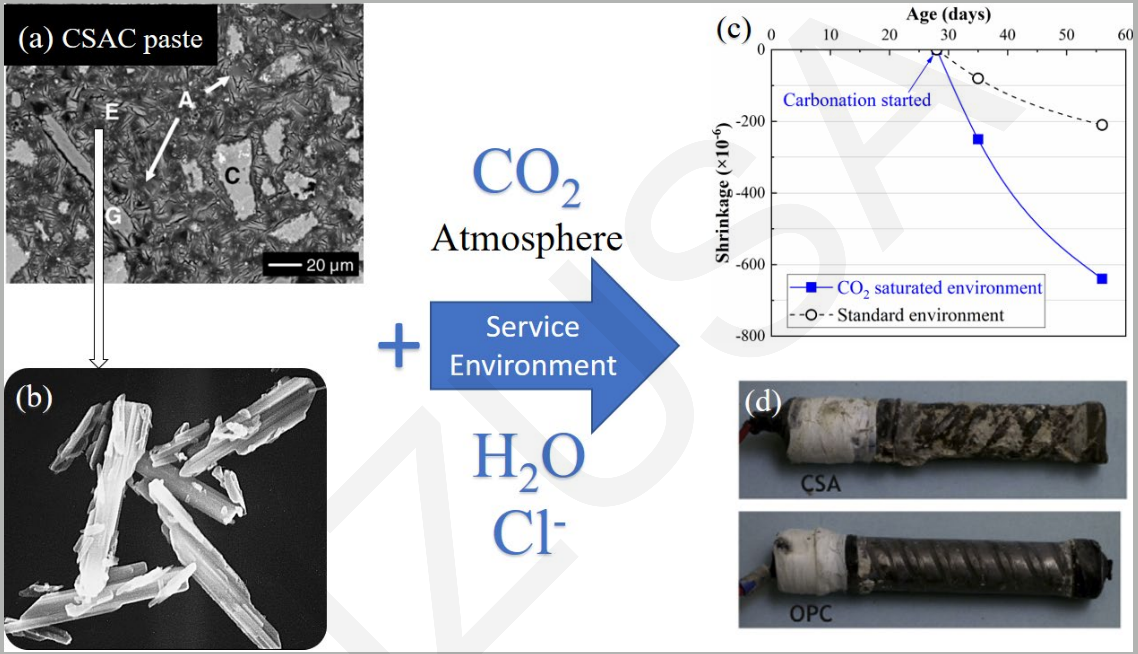


Fig 1. Carbonation and steel corrosion in CSAC concrete: (a) SEM image of CSA paste hydrated for 16 h (C=CSA clinker, G=gypsum, E=ettringite, A= aluminum hydroxide)(Winnefeld and Lothenbach, 2010); (b) SEM image of ettringite(Zhou and Glasser, 2000); (c) Dimensional stability of CSAC mortar over time (after a 28-d curing period) in the standardized environment and in a carbon dioxide saturated environment, *w/c*=0.78(Mechling, et al., 2014); (d) Examples of steel bars extracted from CSAC and PC concrete specimens after 1 year exposure, showing different extents of corrosion(Carsana, et al., 2018).

# Carbonation

- There is a lack of consensus among researchers regarding the rate of carbonation. Some reported that CSAC-based materials tend to carbonate much faster than their PC counterpart with similar 28-day strength and equivalent cement content, or identical w/c. Conversely, some researchers found that CSAC and PC have a similar rate of carbonation.
- A few studies found that, in terms of resistance against carbonation, CSAC can perform better than PC.
- The overall impact of carbonation on a CSAC system depends on various factors including the w/c, type and amount of $CaSO_4$ blended in the cement, type and amount of SCMs, and the exposure condition.

# Conclusions

- Due to its intrinsic characteristics, CSAC concrete has been shown to perform better than its PC counterpart in several aspects, including rapid early-age strength development, low shrinkage and cracking potential, and resistance to freeze-thaw damage, sulfate attack, and alkali-silica reaction.
- More studies on the durability of CSAC concrete, including both lab-based studies and field exposure tests, are needed to clarify the long-term performance of this material in various service environments.
- Emphasis should be given to a comprehensive examination of CSAC’s resistance against carbonation and steel rebar corrosion because of the susceptibility of ettringite to carbonation and the relatively low pH of CSAC concrete



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