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Recent Advances in ASR Test Methods and Understanding Mitigation Mechanisms, Part 2

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Understanding the role of Supplementary Cementitious Materials in mitigating Alkali Silica Reaction

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LABORATORY OF CONSTRUCTION MATERIALS

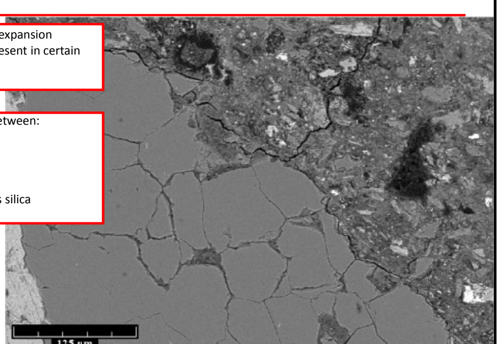
Alkali Silica Reaction

From J. Hideker

Alkali Silica Reaction

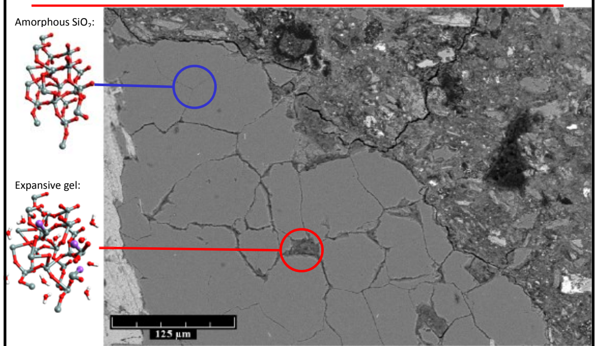
Long-term expansion reaction present in certain concretes

Reaction between:
- Alkali
- Water
- Amorphous silica



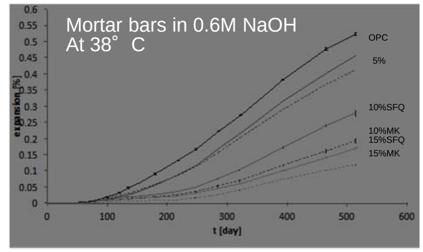
Alkali Silica Reaction

Alkali Silica Reaction



Effect of blended pastes on ASR expansion

SCMs are effective in reducing deleterious ASR (empirical additions):



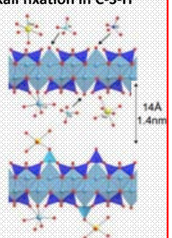
Silicon and Aluminium addition are involved in the reduction of expansion

Aluminium rich SCMs are more efficient against ASR

The exact mechanism by which it happens is unclear!

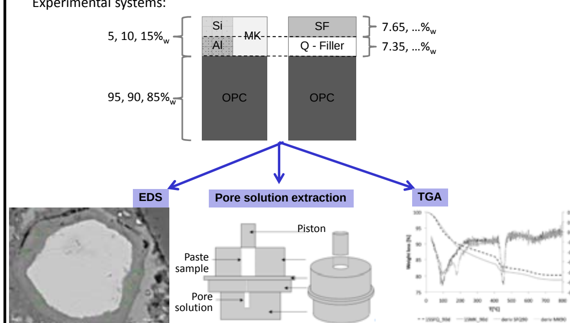
Presentation outline

Influence of Si and Al on alkali fixation in C-S-H



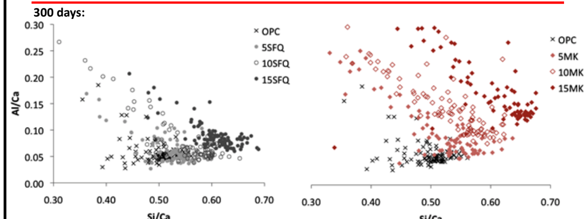
Systems studied

Experimental systems:



C-S-H EDS analysis

300 days:



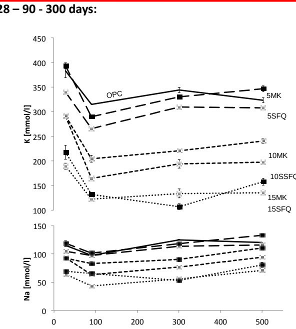
The Si/Ca increase with increasing substitution for both systems (MK and SF-Q)

The Al/Ca is constant for SFQ at all substitutions levels and increase with MK substitution

Pastes can be compared in term of pore solution concentration

Pore solution analysis

28 – 90 - 300 days:



- Lowering of pH is confirmed

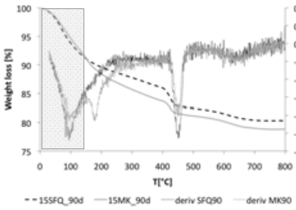
- No improve of fixation is observed up to 2 years in Al rich systems

Al doesn't increase the alkali fixation capacity of C-S-H in blended pastes!

→Another phenomena is involved to control ASR in presence of Al!

C-S-H fixation capacity estimation

Due to difficulties to quantify all the phases in presence in the blends (XRD/EDS/TGA), a comparative study was done, using the TGA water loss between 30 and 150° C, corresponding to the main C-S-H water loss.



(Bound alkalis)

=

(Total alkalis of the system)

—

(Amount of free alkalis)

(Amount of free alkalis)

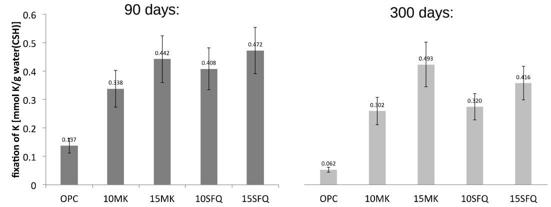
=

(Batch water) – (Total bounded water(800° C))

X

(Alkali concentration from the pore solution)

C-S-H fixation capacity estimation: comparative

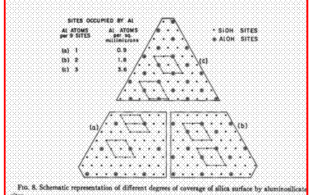


Comparatively, the fixation capacity of SFQ and MK are similar. Aluminium has no influence on the fixation capacity of alkalis

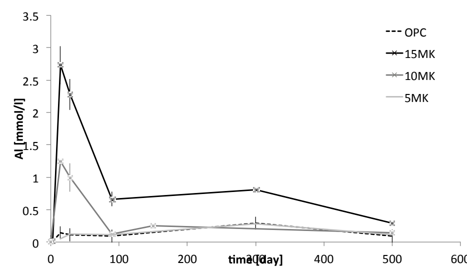
→New approach: focus on the aggregates

Presentation outline

The effect of aluminium on silica dissolution



Pore solution composition of MK pastes



MK systems provide aluminium ions in the pore solution – A peak of aluminium appears during the first 90 days

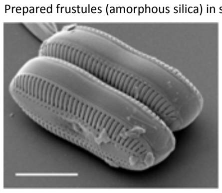
Silica dissolution in presence of aluminium ions

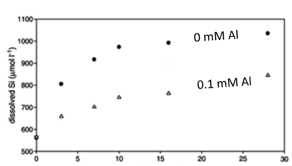
New approach: Focus on the aggregates

Marine chemistry and geology:

« Metal ions, particularly Al, reduce the rate of dissolution of amorphous silica» [Lewin, 1961]

Prepared frustules (amorphous silica) in sea water with and without Al: [Koning, 2007]





"only 1.35 Al atoms/nm^2 was adsorbed (less than one atom layer), and this was sufficient to minimize the solubility of silica"

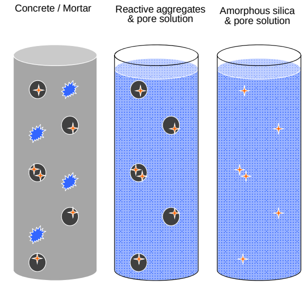
[Iler, 1973]

Multiscale approach

Is this mechanism present in concrete systems?

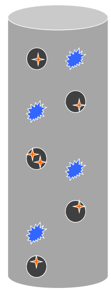
High alkalinity – Ca saturated

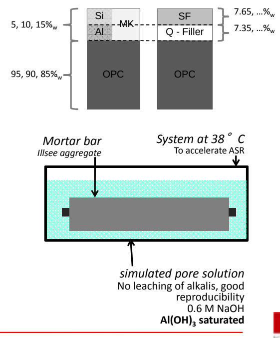
Multi scale approach:



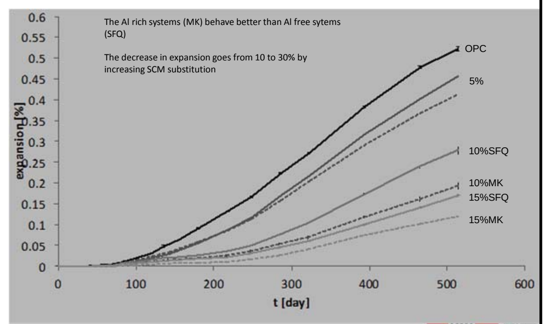
Mortar expansion test

Concrete / Mortar

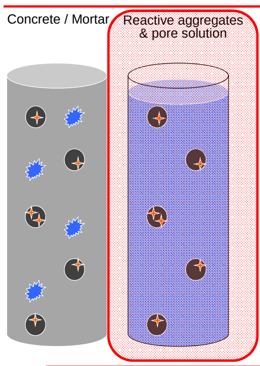




Mortar expansion test



The effect of Al on silica dissolution



Solutions:

-Al ions concentrations corresponding to blended pastes
(0mM / 4mM / 10mM / 30mM / saturated)

- 38° C / 60° C

- Portlandite saturated

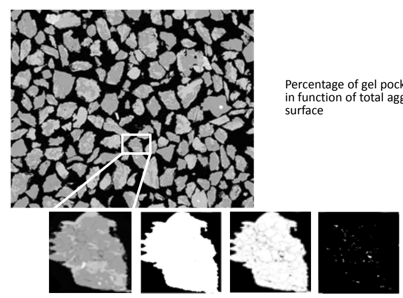
-0.6 M NaOH

Aggregate:

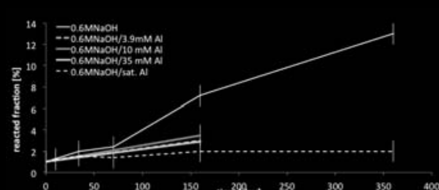
- Reactive Swiss Alps aggregates

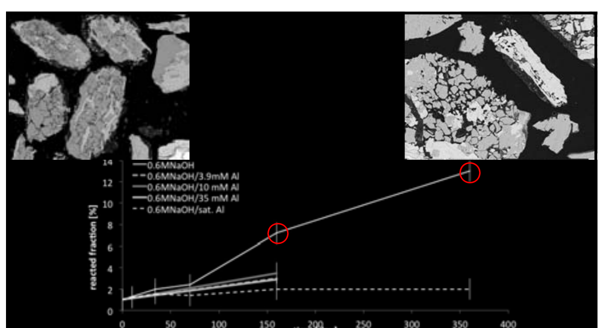
Reactive aggregates test

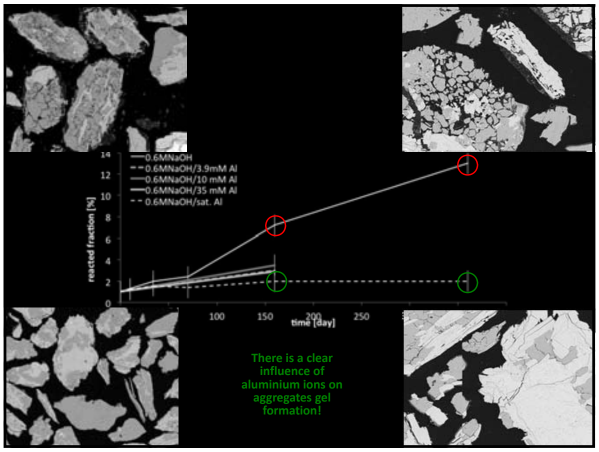
Reacted fraction analysis (SEM-Image analysis):
[Ben Haha & al.]



Percentage of gel pocket surface in function of total aggregate surface

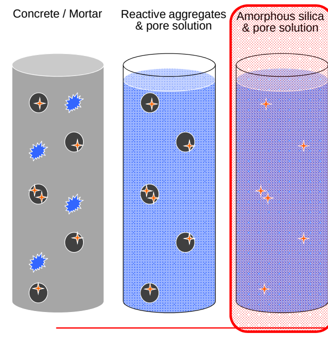


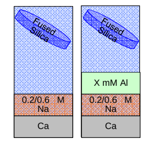




Fundamental study on silica

How does Al incorporate on SiO_2 in paste pore solution conditions?

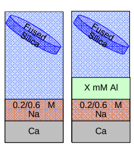


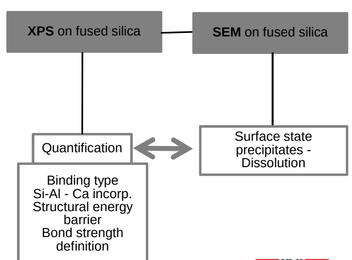


Conc. $Al(OH)_4^-$	0.6/0.2 M NaOH	XPS/SEM analyses
0 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days
1.5 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days
2.5 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days
5 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days
10 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days
15 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days
20 mM	CH sat/CH free – 20°C	14 / 28 / 60 / 90 / 120 days

Fundamental study on silica

How does Al incorporate on SiO_2 in paste pore solution conditions?
-fct of alkalinity
-Ca saturated

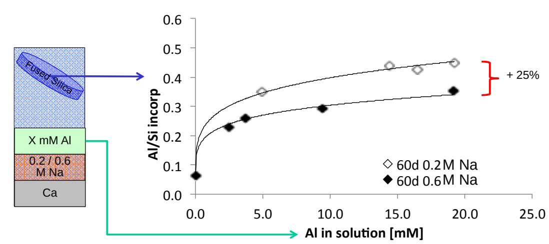




Aluminium incorporation

Aluminium is incorporated on the surface of silica

Higher incorporationat lower pH (at 28 / 60 / 120 days)

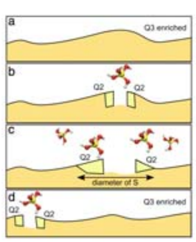


Proposed Mechanism

Mechanism of dissolution of amorphous silica is similar to quartz
if considered in term of chemical bounding

Dissolution of Q3 species make appears a Q2 surface, more reactive → Q2 group retreat (step retreat like)

[Dove, 2008]



Proposed Mechanism

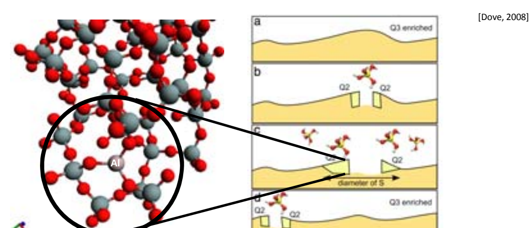
$Al(OH)^-_4$ co-adsorb with Na^+
→deprotonated silanol groups are associated with Na^+ sorbed in the outer-sphere plane

[Labrid & Duquerroix 1991, Bickmore 2005]

Al is incorporated in the silica framework [Koning, 2007]

The Al ion **stabilize** the dissociated form of terminal silanol [Trombetta, 2000]

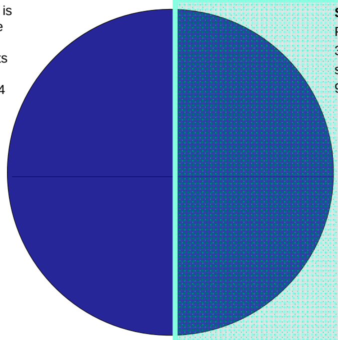
[Dove, 2008]



The effect of aluminium on silica dissolution – « 4 sides test »

The aim of this test is to provide the same initial surface state for all the treatments

Differences on the 4 sizes were visible only after 90 days



Step 1:
Pre treatment:
30 mM Al / 0.2M Na solution
90 days

The effect of aluminium on silica dissolution – « 4 sides test »

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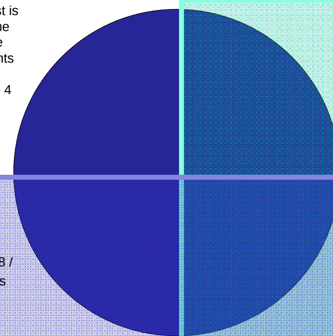
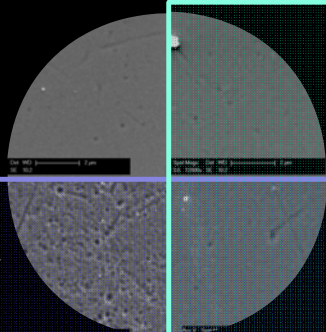


Step 1:
Pre treatment:
30 mM Al / 0.2M Na solution
90 days

Step 2:
Post treatment:28 / 60 / 90 / 120 days
0.6M Na solution

90 days post treatment:



Step 1:
Pre treatment:
30 mM Al / 0.2M Na solution
90 days

Step 2:
Post treatment:28 / 60 / 90 / 120 days
0.6M Na solution

Conclusion

It was showed that the **aluminium present in the C-S-H** of blended pastes **doesn't decreases the alkalinity** of the system

Al incorporation and effect was successfully showed for concrete condition

The mechanism controlling silica dissolution in presence of Al was partially explained and confirmed

Al is **incorporated in the silica framework** and probably stabilizes the step retreat dissolution of the Q2 species

The **alkalinity has an influence** on the aluminium incorporated fraction. The lower alkalinity present a higher aluminium incorporation

→ Aluminium effect has to be combined with an alkalinity reduction to be more efficient (visible on expansion curves?)

Approximation of dissolution rate? → prediction of gel formation rate→ expansion!