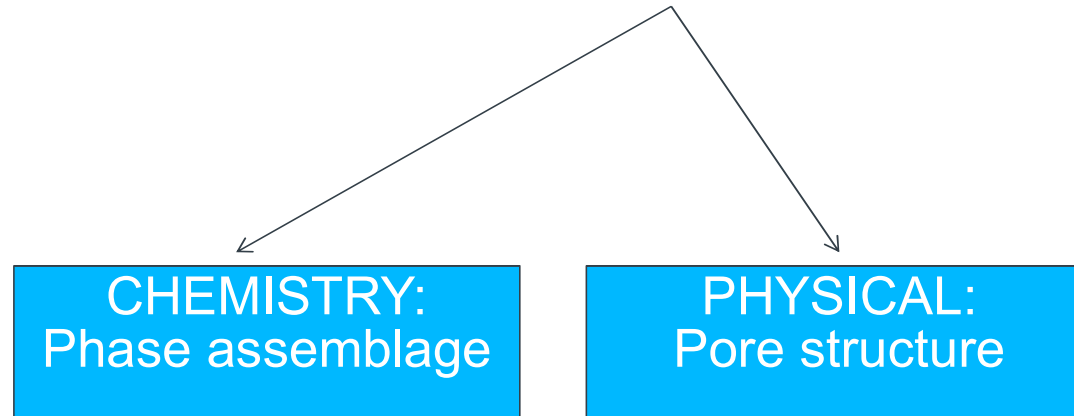


Durability

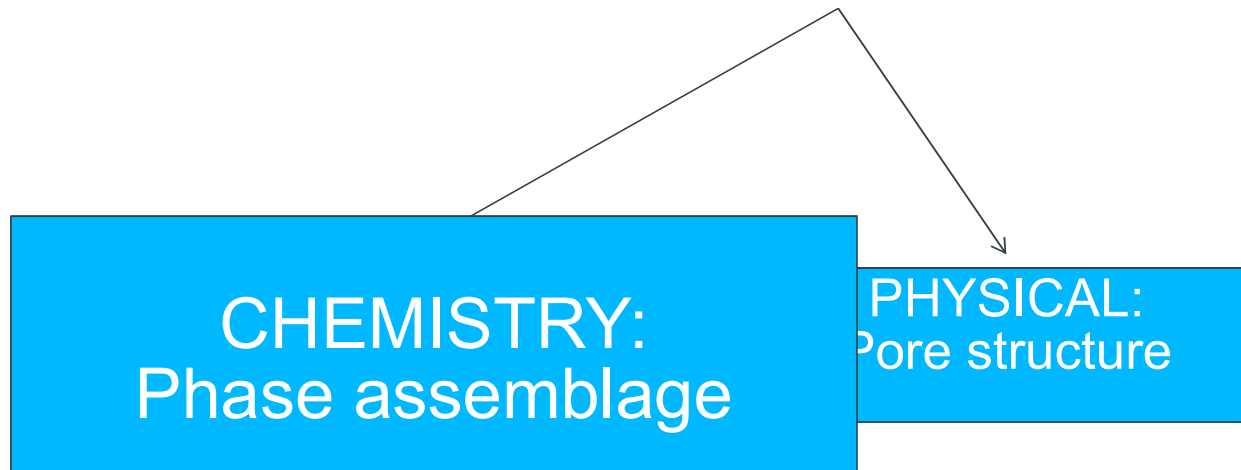
Generic approach to durability

Durability determined by microstructure:

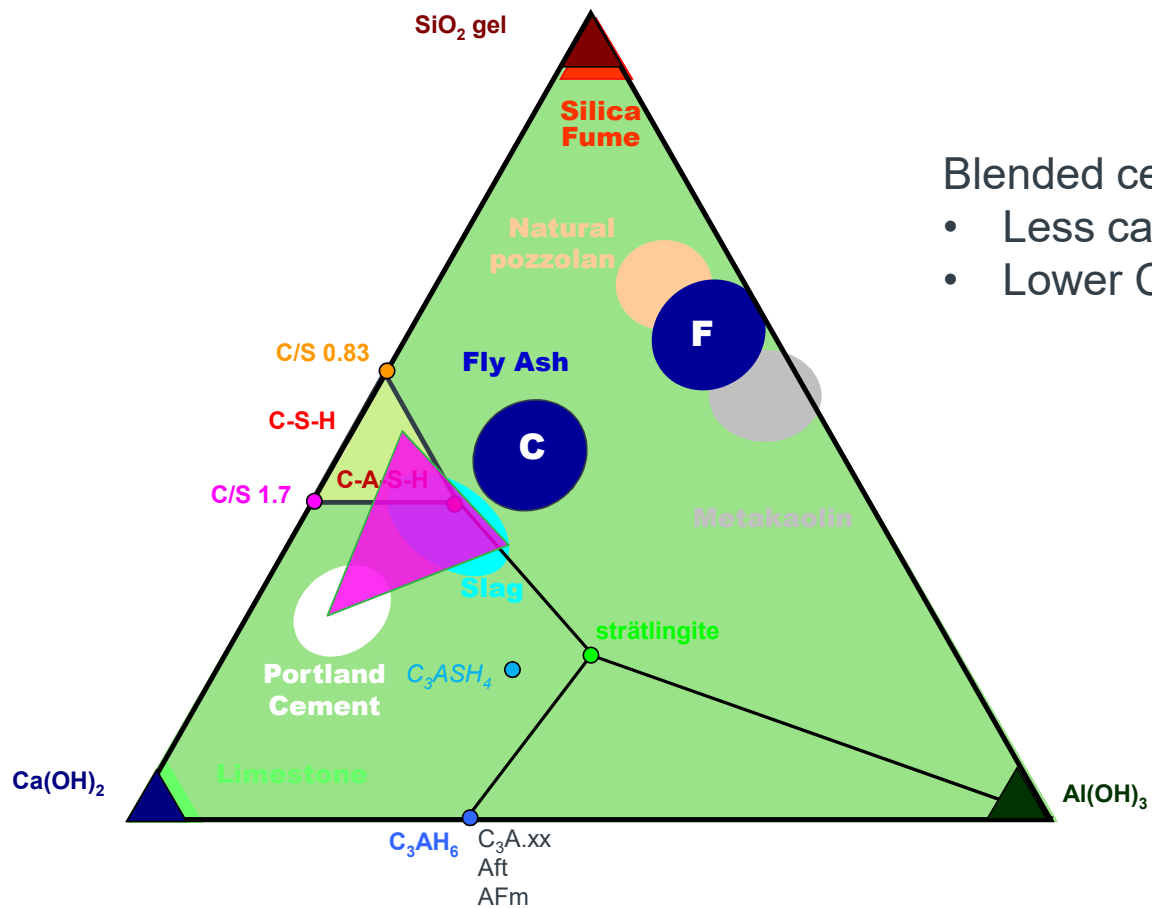


Generic approach to durability

Durability determined by microstructure:

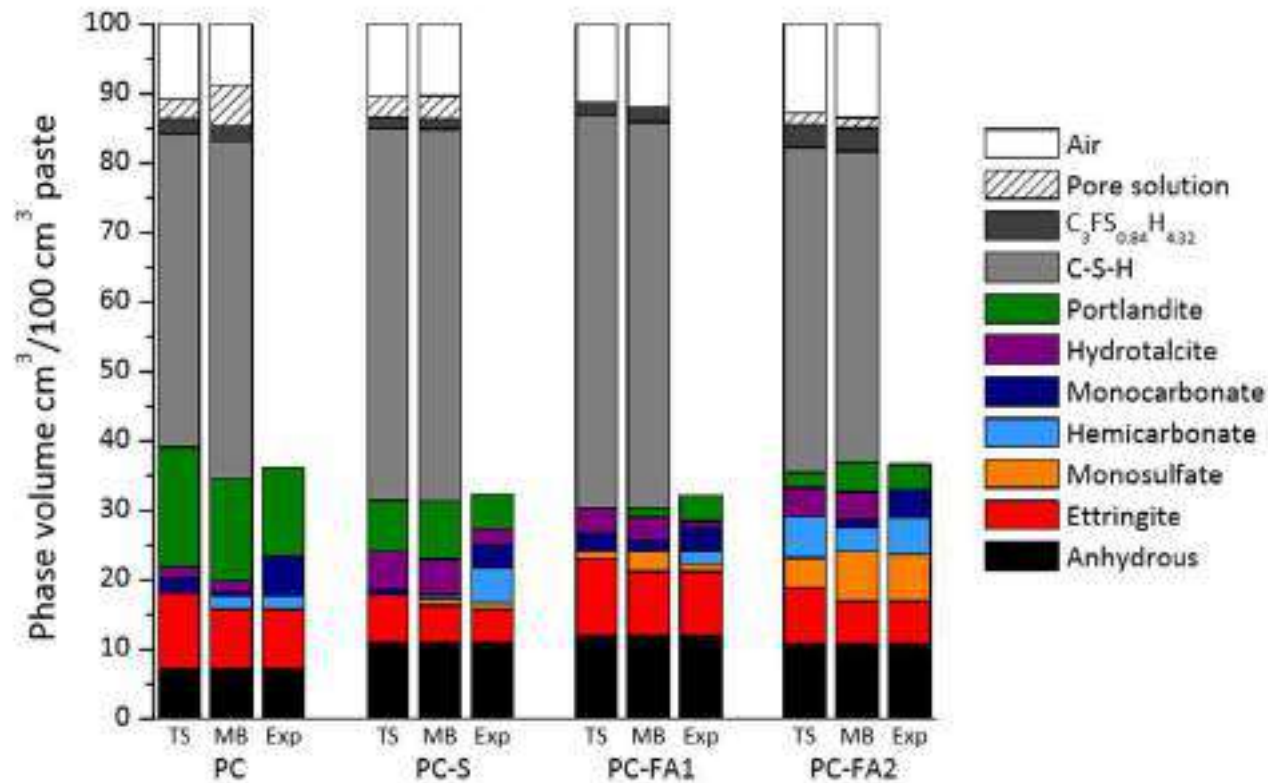


Main components CaO-SiO₂-Al₂O₃



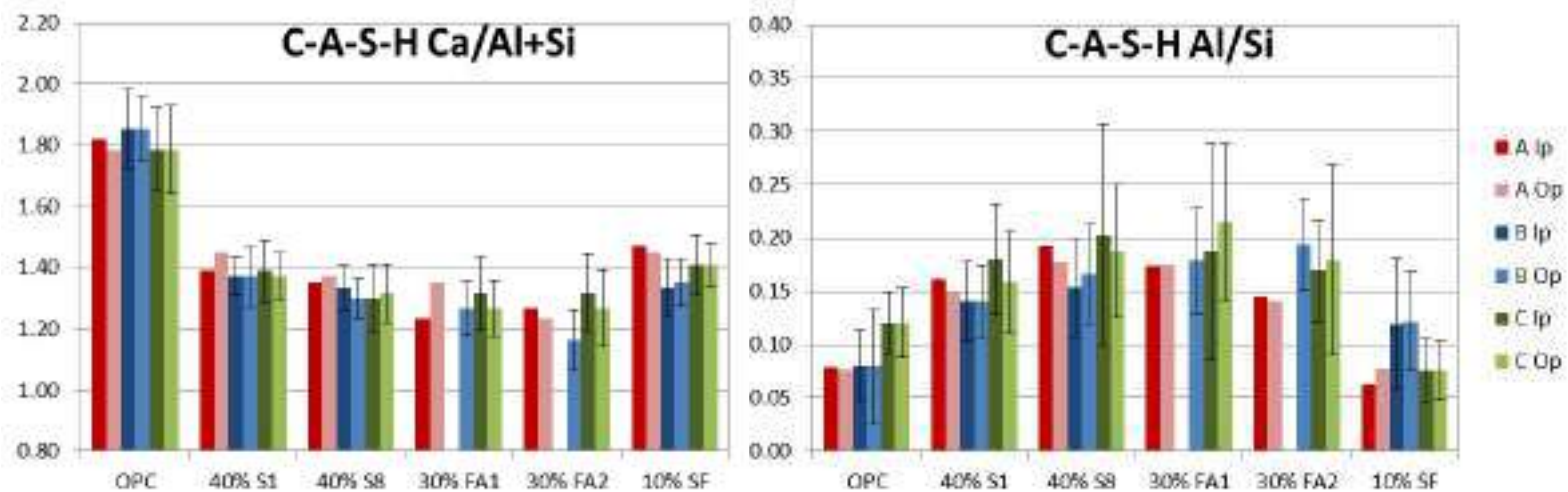
Blended cements:

- Less calcium hydroxide
- Lower Ca/Si C-S-H



Durdzinski et al CCR 2017

Composition of C-A-S-H after 4-5 years

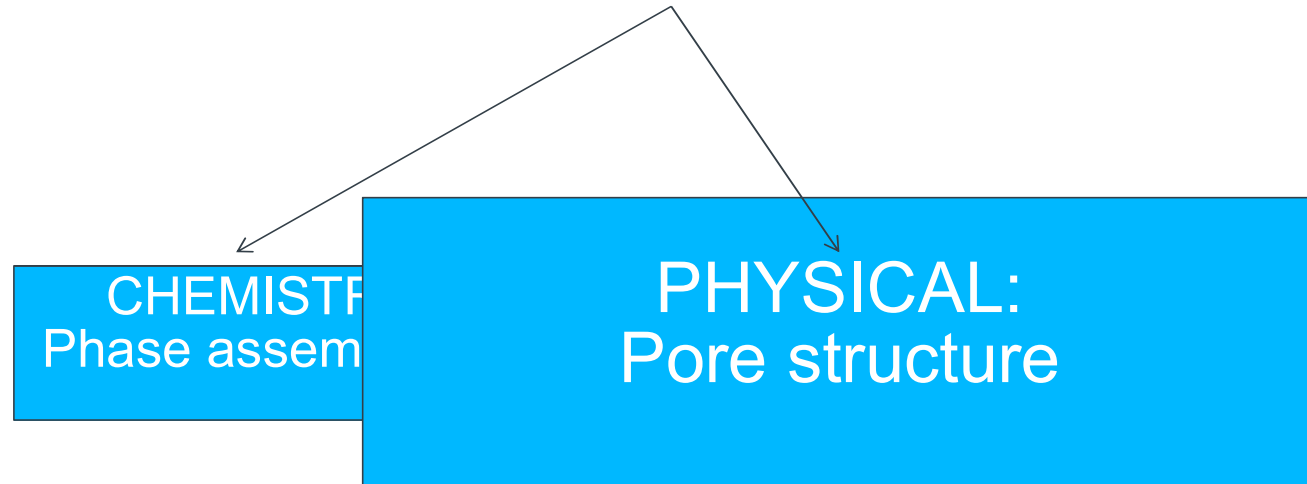


Very similar C/S ratios – stabilised by presence of Portlandite
Al usually higher, approaching Al/Si = 0.2 (except SF no Al)

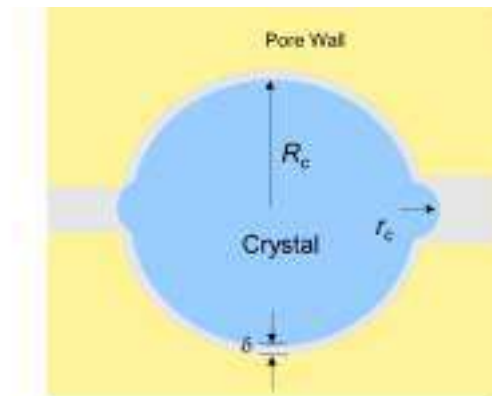
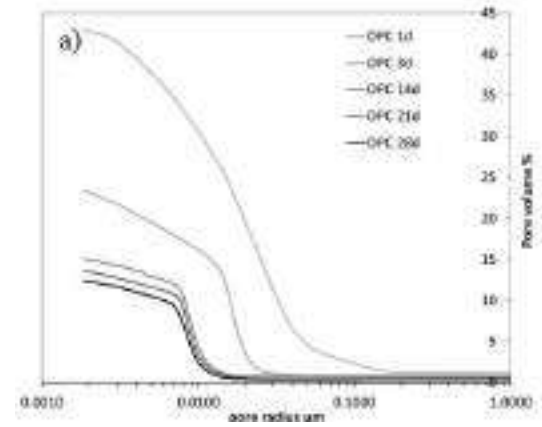
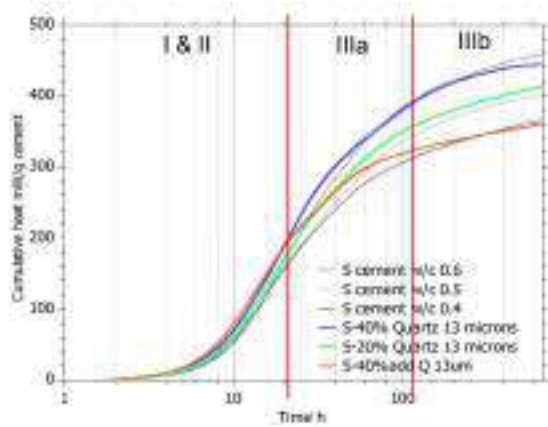
Degradation phenomena	Impact of hydrate phases
Chloride ingress	Aluminate containing hydrates react to bind chloride ions in Friedel's salt, Chloride also absorbed on C-S-H
Carbonation	Calcium oxide in all hydrates will eventually form calcite leaving hydrated silica and alumina gels
Sulfate ions	AFm phase react with sulfate ions to form ettringite, if these phases are confined within the C-S-H and the solution is supersaturated expansion may occur
Alkali silica reaction	Absorption of alkali ions on C-S-H determine the pH of the pore solution. Reactive alumina from SCMs may also directly inhibit dissolution of reactive amorphous or poorly crystalline silica

Generic approach to durability

Durability determined by microstructure:



Limiting pore size

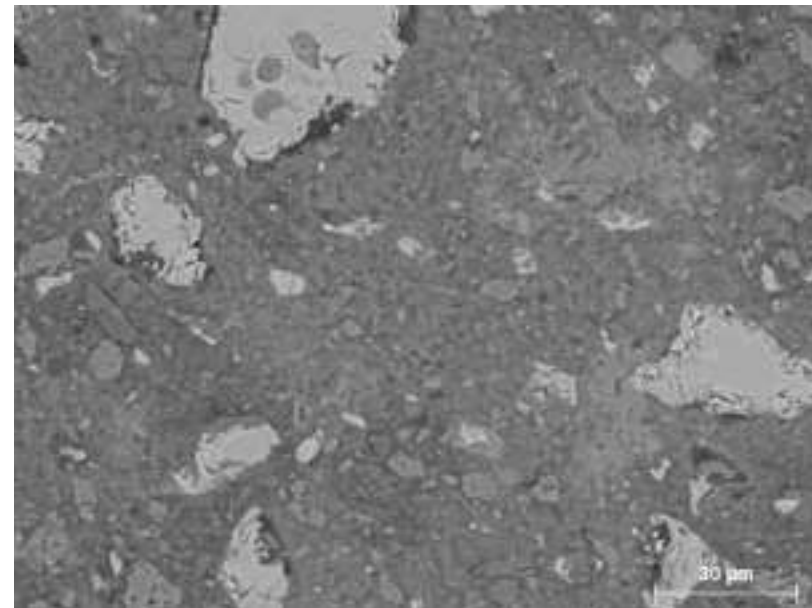
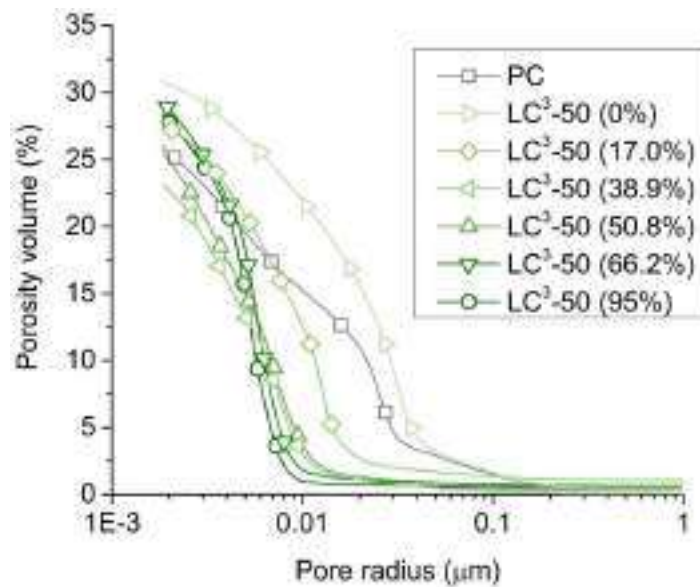


Limiting pore size for crystal growth about 10 nm

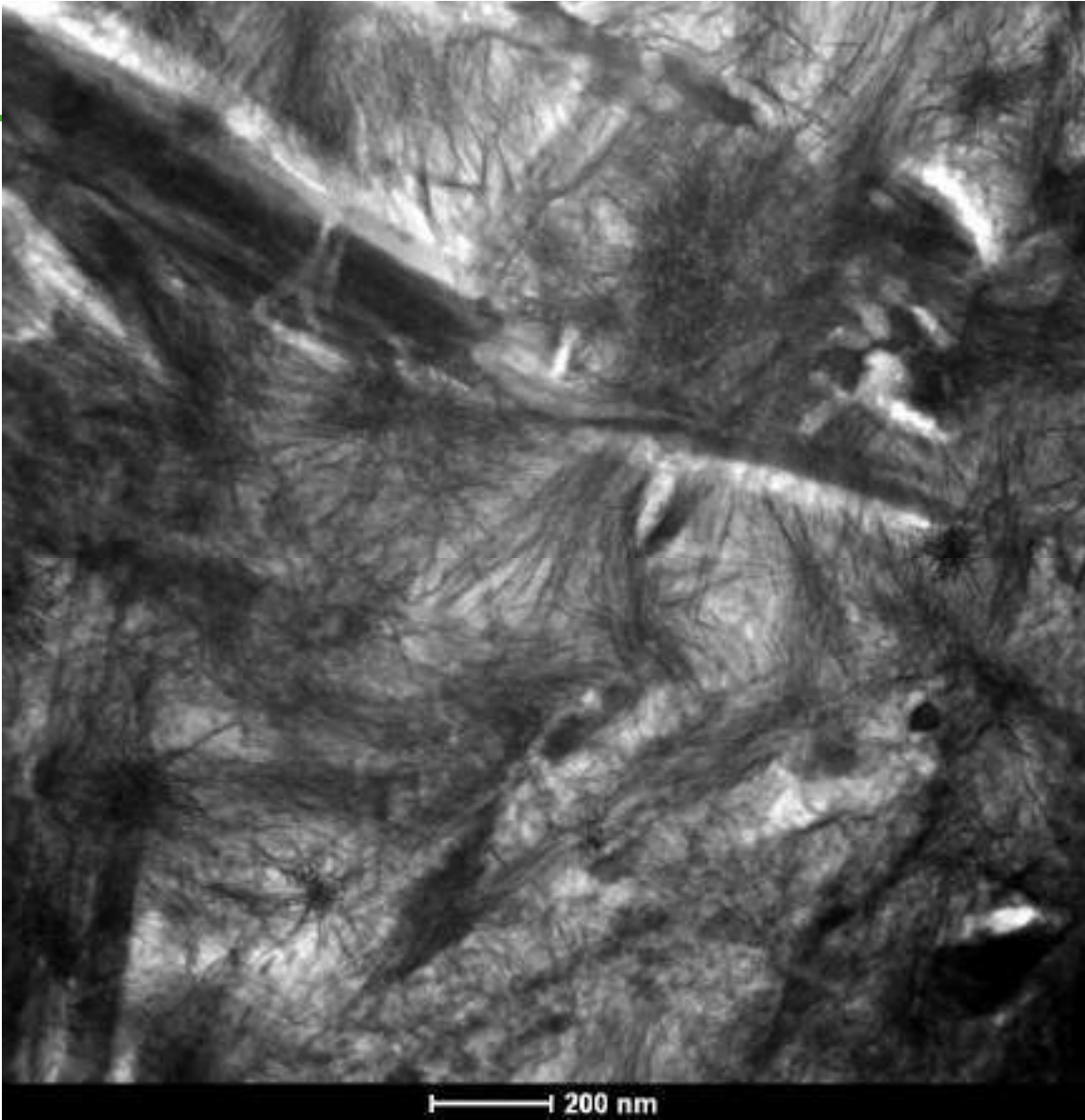
Whether this is reached depends on:

- w/c
- Curing
- Reacting phases

Most important aspect is
the very strong refinement of porosity



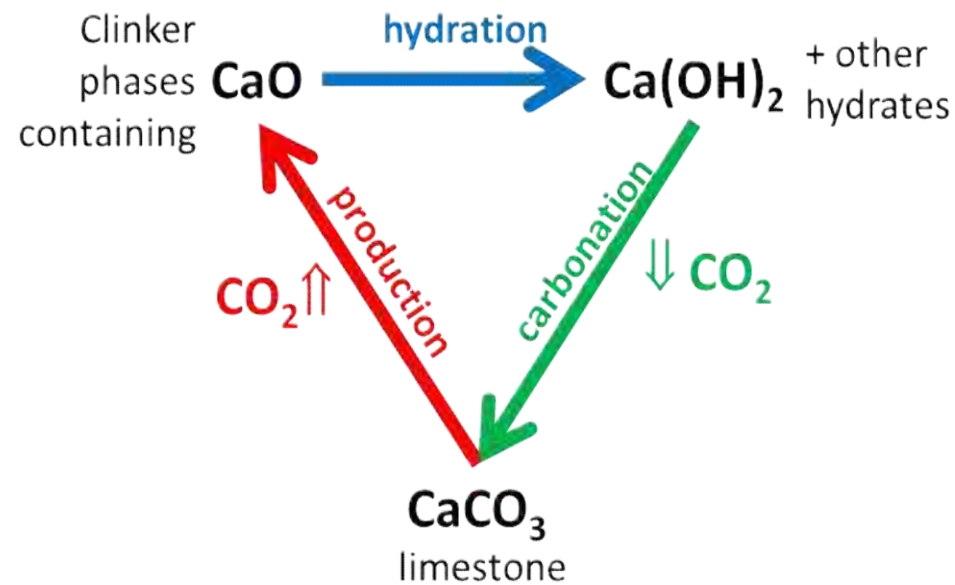
28 days

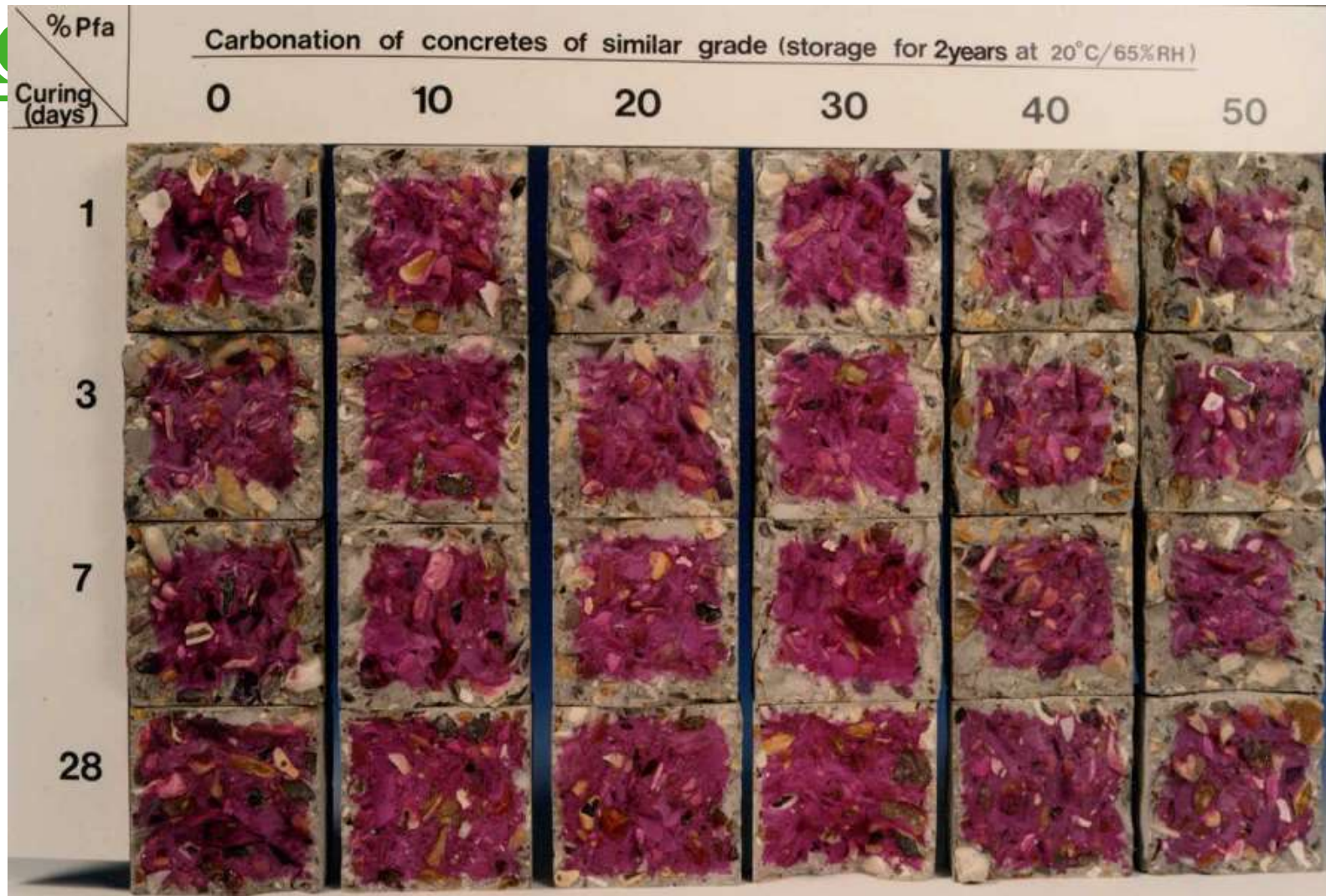


200 nm

Carbonation

Steel protection comes from high pH: linked to calcium content and therefore CO₂

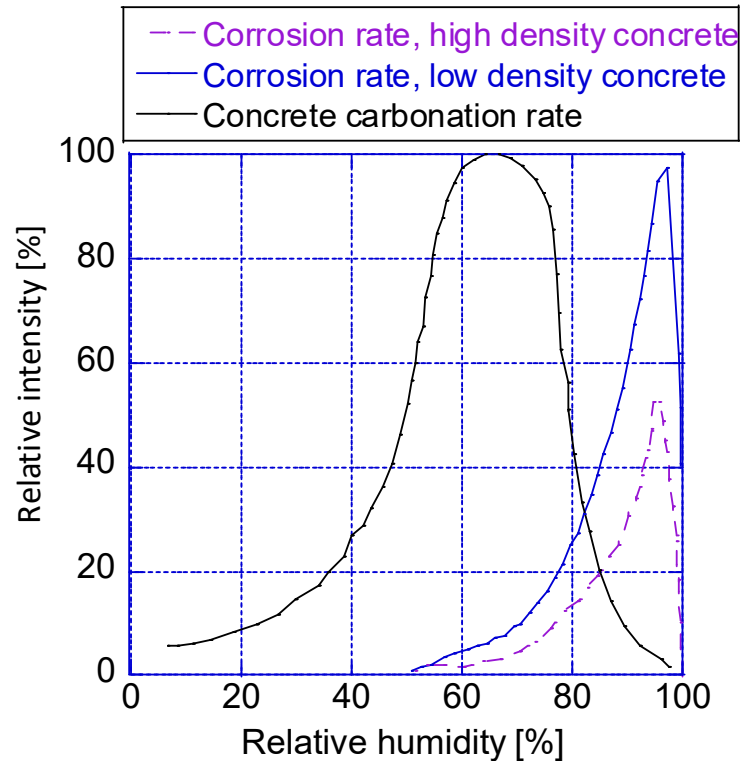




Reduction of buffering can be offset with good curing

From BRE via MDA Thomas, UNB

Practical risk of carbonation corrosion ?

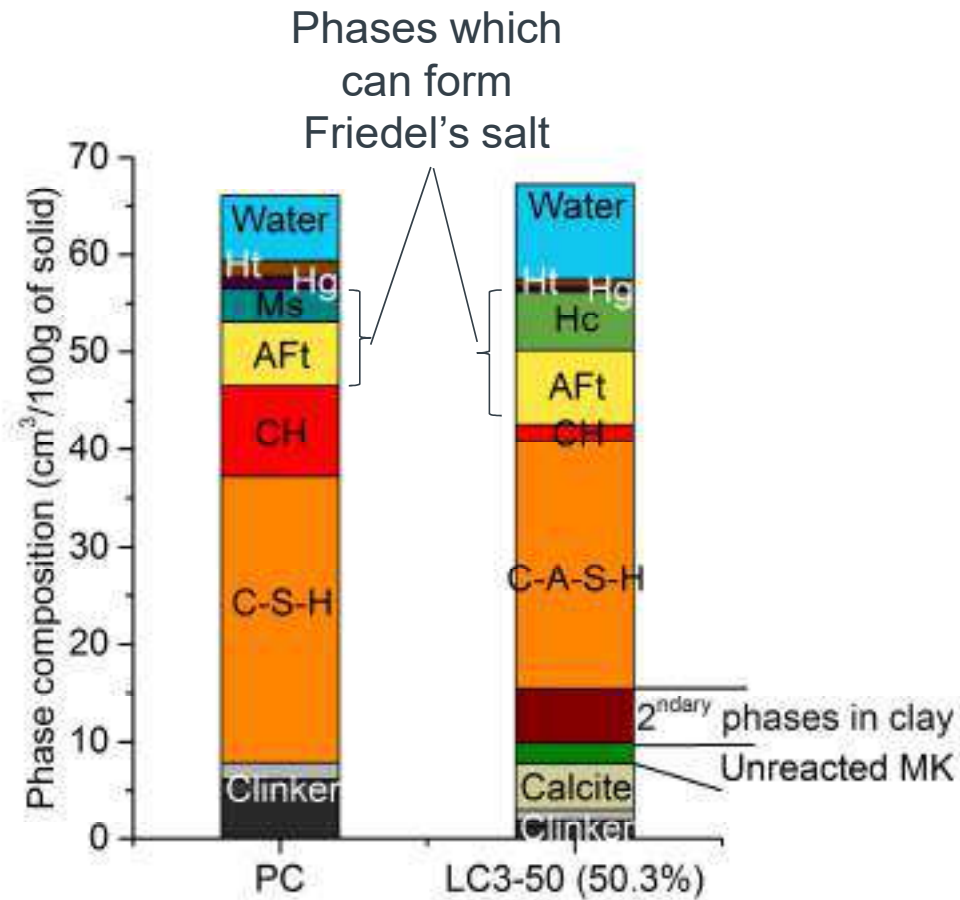


- » Carbonation takes place in environments which are too dry for active corrosion
- » Conversely conditions with enough humidity for active corrosion will only carbonate very slowly
- » Can be dealt with by correct design and cover depths

Chloride ingress

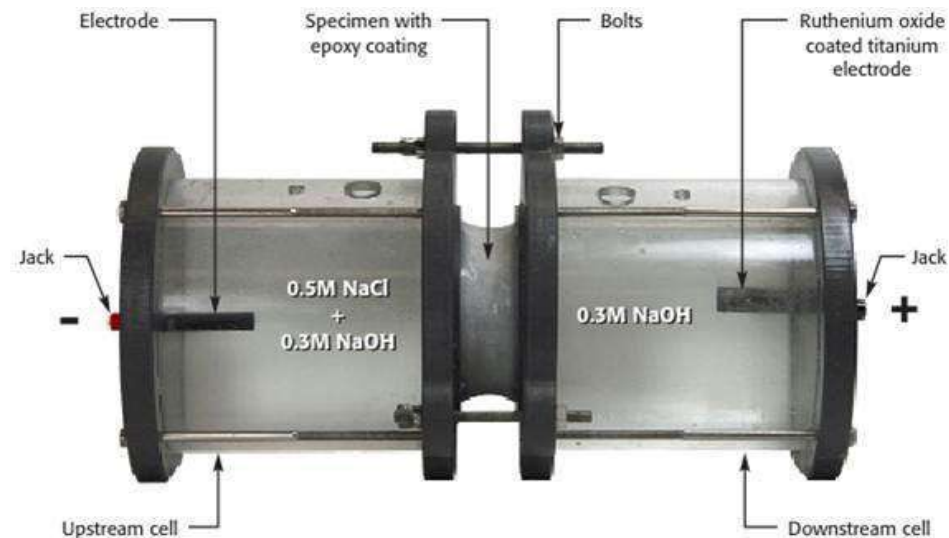
Example of LC3 binders

Phase assemblage



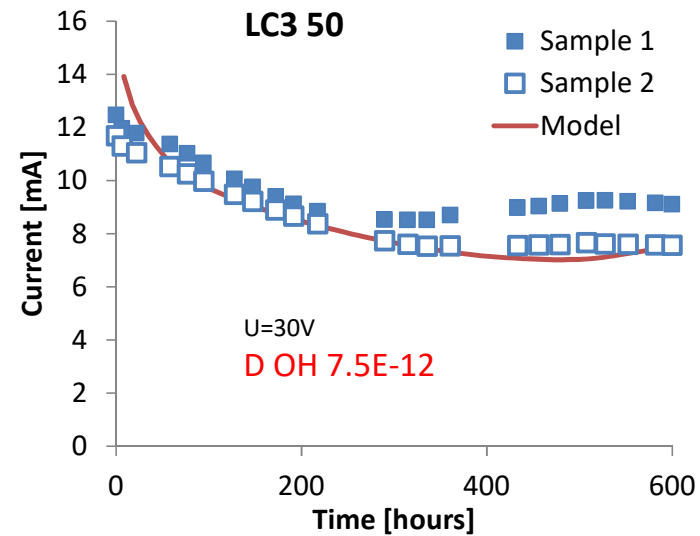
Chloride migration test

- ASTM C1202-97: too high voltage, self heating ⇒ Modified version of the test, from SIMCO
 - Lower voltage, run for at least 10 days
Current and Voltage monitored daily
 - Use in combination with model to estimate diffusion coefficient of ions in cementitious materials

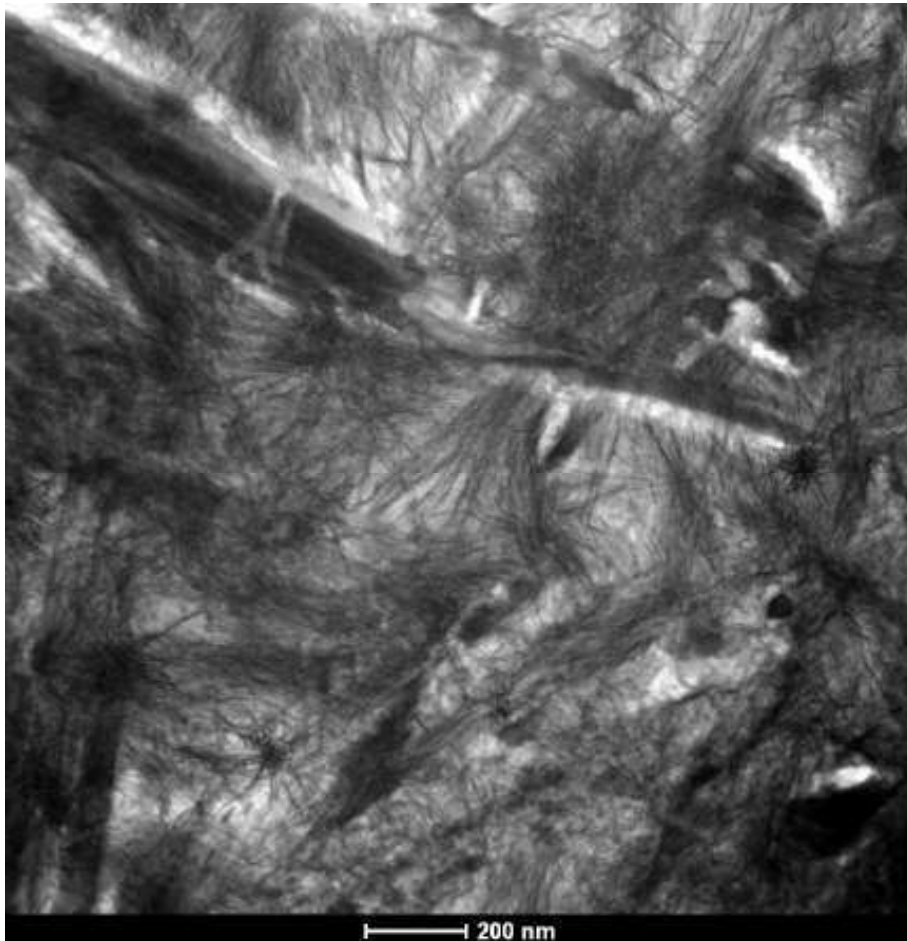


M. Antoni, PhD thesis, EPFL, 2013

Migration test: summary



- Stadium Model shows an improvement of diffusion coefficient by **factor 10 between PC and LC3-50**



10 nm =
40 water molecules

~5 layers are
“structured”
Mobility of 4th layer
2x less than free water

What about charged
ions?.

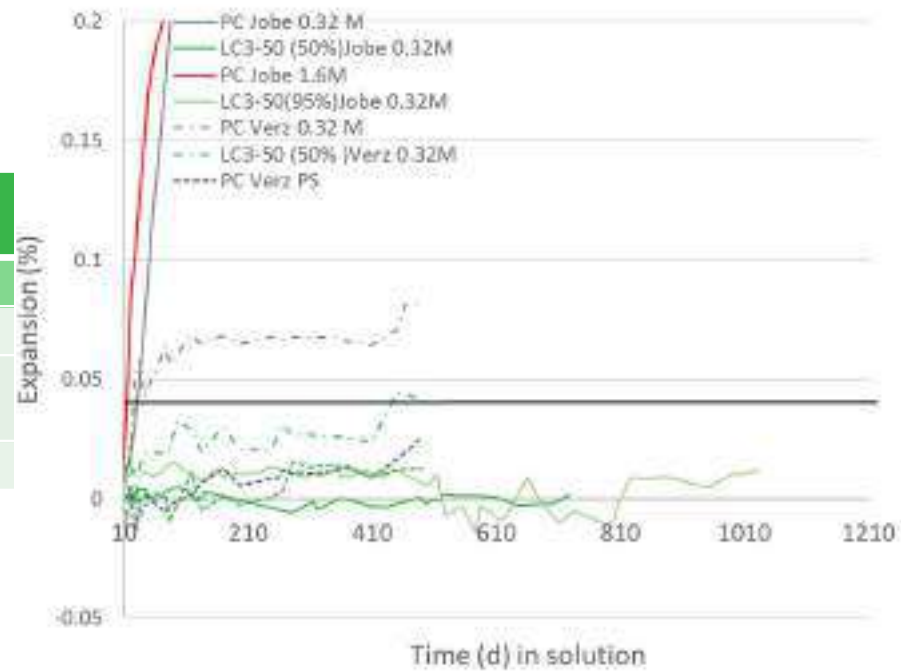
Alkali Silica Reaction

ASR

➤ Expansion vs time

Jobe (high reactive)		Verzasca (low reactive)	
PC	LC3-50	PC	LC3-50
0.32M	0.32M	0.32M	0.32M
1.6 M		Pore Solution	PS
		1.6M	

-Immersed in solution after 28days curing
-Stored at 38°C

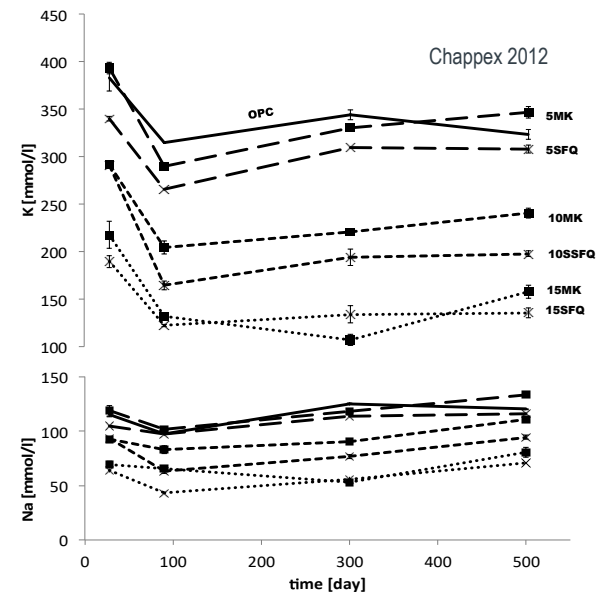


Impact of alumina silicate SCMs

- SCMs containing silica and alumina are very effective to prevent ASR
- Silica lowers the Ca/Si ratio of the C-S-H by the pozzolanic reaction
- This in turn lowers the pH of the system:

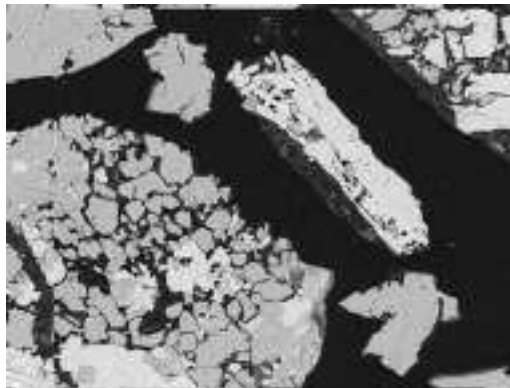
Here we can see that just 15% of metakaolin or silica fume reduces the concentration of alkalis by a factor of 3

But as for low alkali cements this lowering of the pH seems only to delay rather than prevent ASR

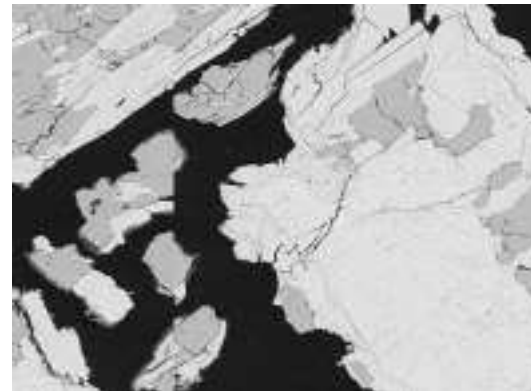


Impact of alumina rich SCMs

- It has been realised for some time that SCMs containing alumina are more effective
- The work of Chappex at EPFL showed this was because alumina adsorbs on reactive sites of reactive silica and inhibits the dissolution:



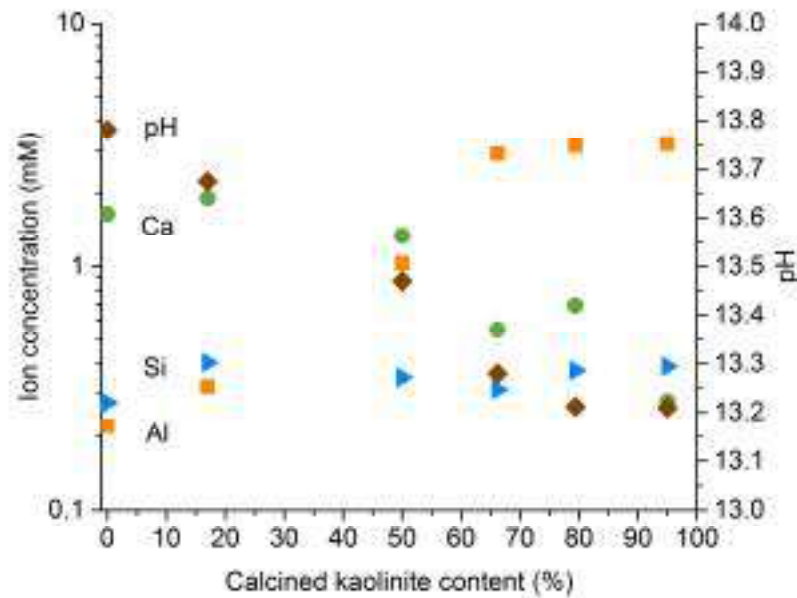
Dissolution of aggregates after 1 year in alkaline solution, no alumina



Dissolution of aggregates after 1 year in alkaline solution, with alumina

Chappex 2012

Alumina in solution increases with kaolinite content



Pore solution
compositions
from LC³
systems

Avet 2017

Workability

LC3

- Limestone and calcined clay are both much softer than clinker
- With intergrinding, high blaine and clinker is likely to be underground. But situation can be improved by separate grinding or addition of calcined clay at separator
- However effect of limestone and impurities in clay has positive influence
- Good flowable concrete can be obtained with use of superplasticizers
- In some formulation SP dosage may even be less



Concluding remarks

- Future cements will be based on Portland cement clinker with increasing levels of incorporation of SCMs
- Calcined clays are the only realistic option for extending the use SCMs
- Workability can be mastered
- Calcined clays have very positive impact on:
 - Chloride ingress
 - ASR
- Possible downside is faster carbonation, but there is a low risk of carbonation induced corrosion in most concrete
- If we are serious about more sustainable concrete we need to use cements with lower CO₂ emissions, e.g LC³ clinker/ calcined clay / limestone blends

Thank You