

# Sulfate attack on cement-based materials

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Qiao WANG, PhD at LMC EPFL, in Switzerland

E-mail: [qiao.wang@epfl.ch](mailto:qiao.wang@epfl.ch)



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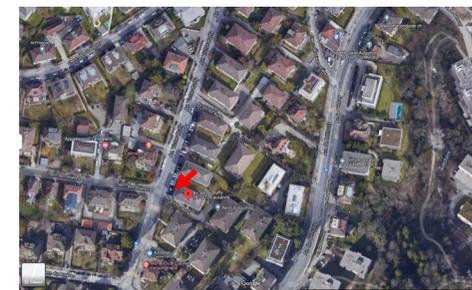
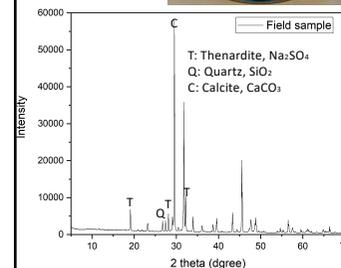


## 1. Background: What we see in the field



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Thenardite: 36 %  
Quartz: 4 %  
Calcite: 57 %

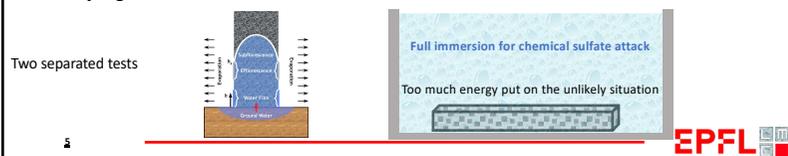


In pully, Lausanne  
Can we really see the same manifestations in the laboratory tests?



## 1. Background

- ❖ Current existing test methods/standards are more related to relative large mortar/concrete samples without giving much representative/reproducible results
  - Interesting results are important, but pragmatic in the field is more vital
  - Not easy of using quite complex/large samples to understand the fundamental mechanisms, particularly relying on microanalytical techniques
  - Artificially separate one topic into two items is misleading people
- ❖ Rethink of the proper approach is essential before jumping into this obscured jungle



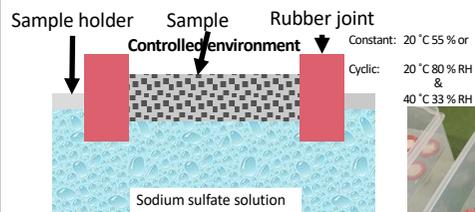
## 1. Background

- ❖ We want to establish a versatile approach to evaluate the sulfate resistance for cement-based materials including two aspects in the same specimen
  - Uniaxial penetration approach is preferred – because it is simpler for characterization & two aspects of sulfate attack can be considered simultaneously
  - Cement paste sample is preferred than mortar/concrete – because the effects of intact aggregates can be excluded & the degradation process is accelerated

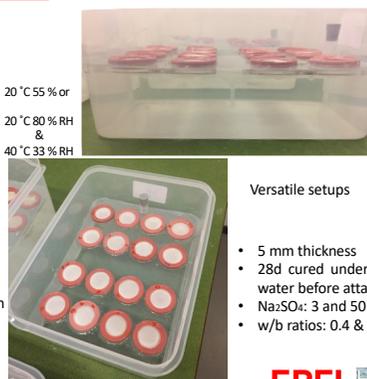


## 2. Methodology

### The new setup

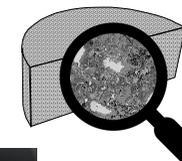


- Uniaxial ingress of sulfate ions and water evaporation
- Practical for experimental analysing methods
- Controlled environmental parameters (RH & T)
- Integrate two possible attacks into one sample



## 2. Methodology

- Expansion at each depth of the specimen's diameter
- Mass measurement is done accompanied with expansion
- Scanning electron microscopy, maps through entire depth



EPFL

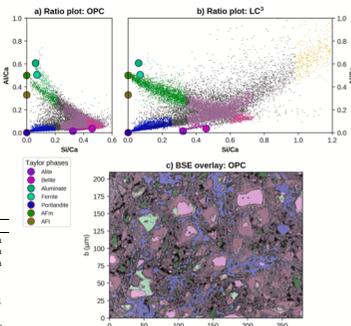
## 2. Methodology

F. Georget, CCR, 2021

### EDXIA

- A quite useful technique to separate specific phases through defining proper atomic ratios in hyper maps
- A spatial distribution of phase can be observed

Phases	Si/Ca	Al/Ca	BSE peak	Others
Portlandite	<-0.2	<-0.2	Hydrate	Na/Ca, K/Ca
Culicite	<-0.2	<-0.2	Hydrate	Na/Ca, K/Ca
Carbonated gel			Hydrate	Na/Ca, K/Ca
Gypsum			Hydrate	S/Ca→1
Ettringite			Hydrate mixes with C-S-H	S/Ca→0.5, Al/Ca→0.33
C-S-H matrix	Variable	Variable	Hydrate	Depends on cement types
Thenardite			Hydrate	Na/S→2



Q. Wang, submitted to CCR

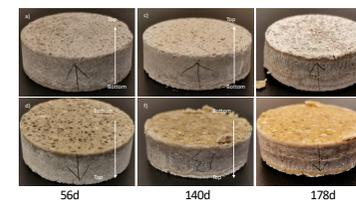


## 3. Application on mortar samples

MPC06-50g-constant

### Visual inspections

- No obvious cracks can be observed until 112 days
- Efflorescence is not seen until 140d
- Longer exposure may be needed in terms of potential salt crystallization attack on top

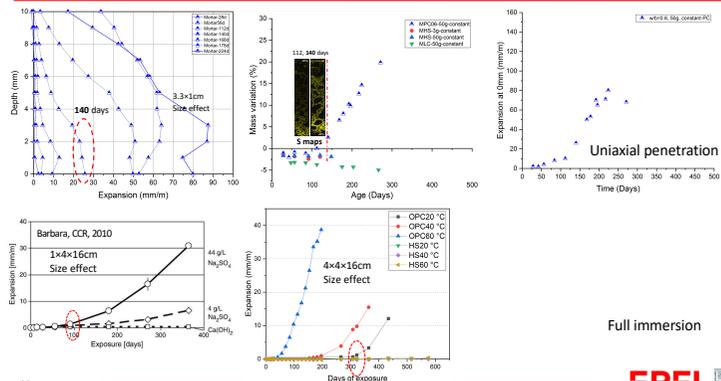


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## 3. Application on mortar samples

Expansions  
Mass variation



Full immersion

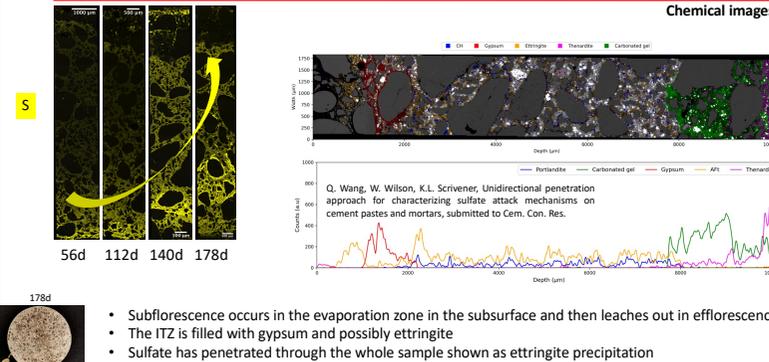


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## 3. Application on mortar samples

MPC06-50g-constant-140d

### Chemical images



178d

56d 112d 140d 178d

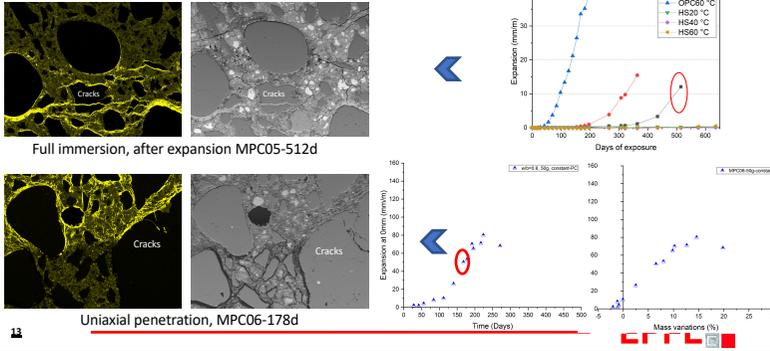
- Subflorescence occurs in the evaporation zone in the subsurface and then leaches out in efflorescence
- The ITZ is filled with gypsum and possibly ettringite
- Sulfate has penetrated through the whole sample shown as ettringite precipitation

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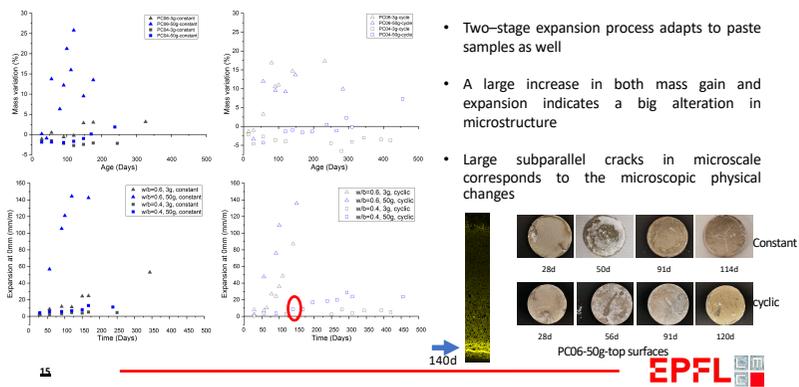
### 3. Application on mortar samples

Nothing far away from our basic knowledge on sulfate attack

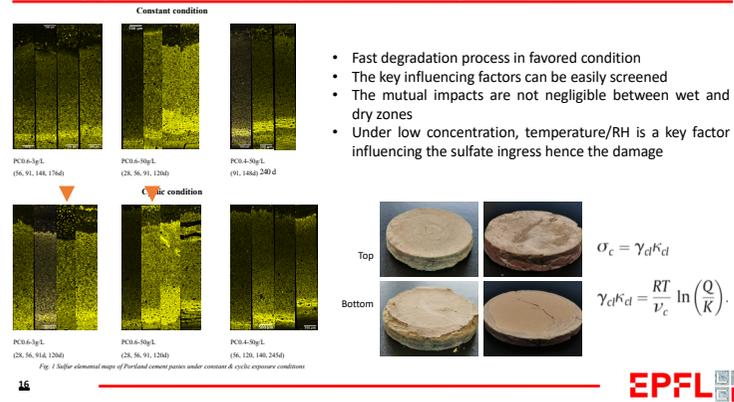


How about the paste samples?

### 4. Application on paste samples – PC

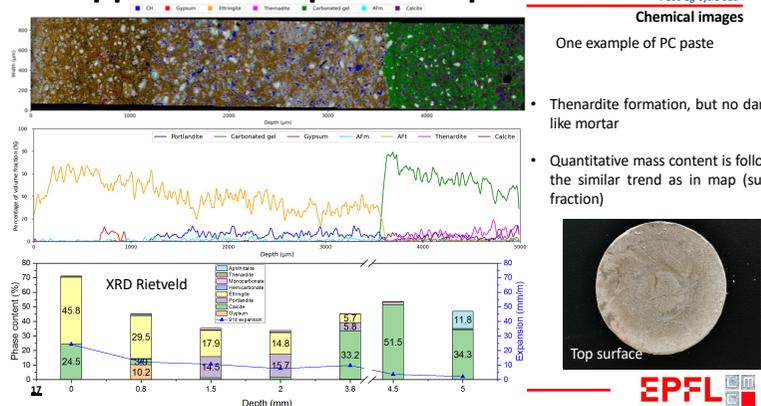


### 4. Application on paste samples – PC



### 4. Application on paste samples – PC

PC06-3g-cycle-91d



### 4. Application on paste samples

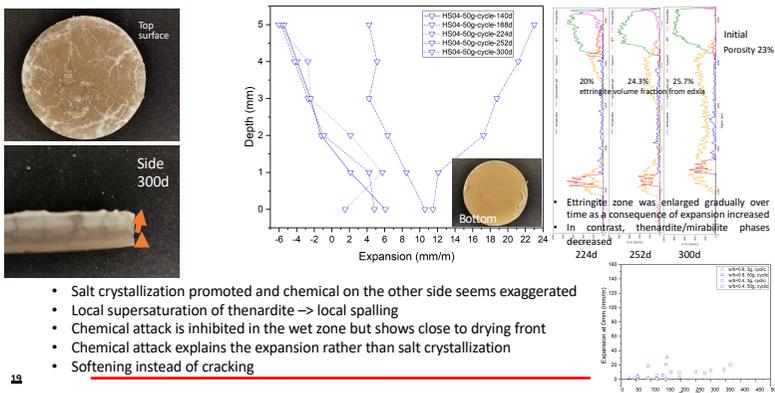
HS cement paste?

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### 4. Application on paste samples – HS

HS04-50g-cycle

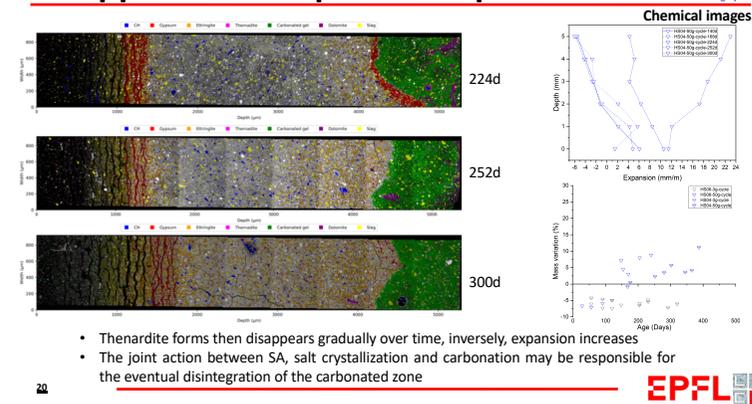


- Salt crystallization promoted and chemical on the other side seems exaggerated
- Local supersaturation of thenardite → local spalling
- Chemical attack is inhibited in the wet zone but shows close to drying front
- Chemical attack explains the expansion rather than salt crystallization
- Softening instead of cracking

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### 4. Application on paste samples – HS

HS04-50g-cycle



- Thenardite forms then disappears gradually over time, inversely, expansion increases
- The joint action between SA, salt crystallization and carbonation may be responsible for the eventual disintegration of the carbonated zone

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### 4. Application on paste samples

LC<sup>3</sup> cement paste?



### 4. Application on paste samples – LC3



- No expansion and cracking at all, but dramatic spalling is followed by efflorescence
- Damage starts locally due to local supersaturation, then propagating uniformly
- Even only constant condition is sufficient for LC3 degrading, surprisingly, no damage is observed under hydrothermal conditions

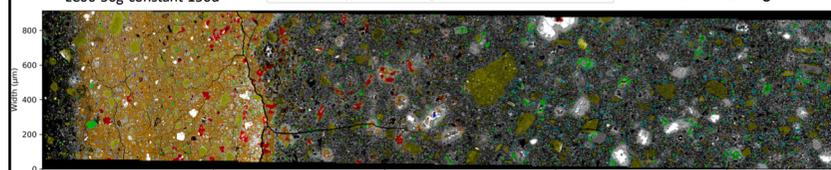


Hydrothermal condition, 140d

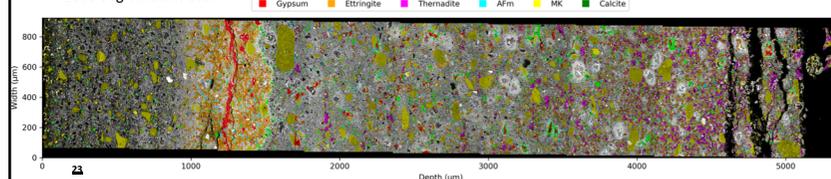


### 4. Application on paste samples – LC3

LC06-50g-constant-150d Chemical images

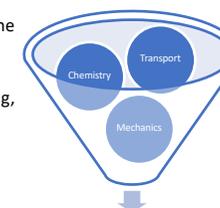


LC06-50g-constant-263d



### 5. Conclusions

- Use cement paste sample does not change the fundamental knowledge we had, more practical for characterization in the lab
- Chemical sulfate attack is largely inhibited in LC3 and HS, however, salt crystallization attack is enhanced with spalling phenomenon
- Lowering concentration can significantly slow down the degradation process
- Lowering w/b ratio can also slow down the degradation
- Hydrothermal exposure is not necessary to cause spalling, constant exposure can do the same



Behaviour of degradation



## 5. Conclusions

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Top  
side



Circumferential cracks appeared but no visible spalling, PC, 150d



Flake-spalling appeared for HS, 350d



Onion like peeling off for LC3, 320d

- They are under the same constant condition with w/b of 0.6, but the damaging manifestations are rather different
- A generic test for PC and blended materials is rather needed than the only conventional test

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Thanks for your attention!

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