Microstructure, mechanical performance, and chloride binding of seawater cured portlandite-calcined clay binders

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Outline

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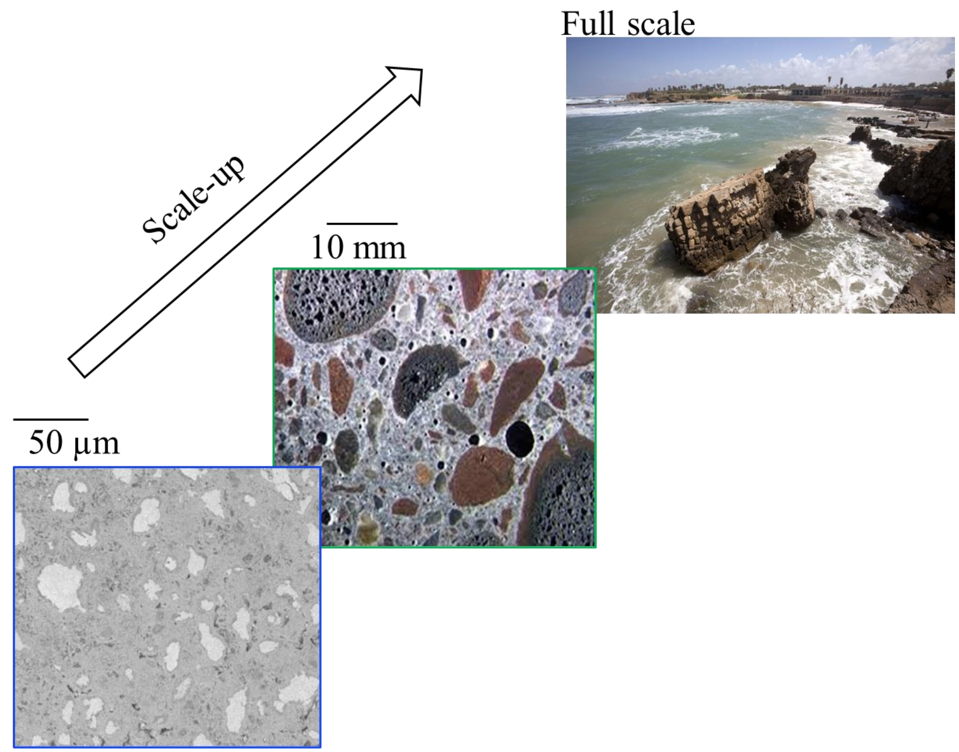
- ❑ Research approach and goal
- ❑ Methodology
- ❑ Sample preparation
- ❑ Experimental results
- ❑ Summary and future direction
- ❑ Acknowledgement



Background and Motivation

- Concrete is used 30 billion tonnes per year.
- It is also responsible for nearly 8% of global anthropogenic CO_2 emissions!
- Modern concrete exhibits poor durability performances and less than 50 years of service life.

Fig. 1: Deterioration of concrete exposed to seawater

Research Approach and Goals

- ‘Roman concrete’ withstood harsh seawater exposure conditions for more than 2000 years.

- It requires lower temperatures (800^{o}C vs 1500^{o}C) and less freshwater for production compared to modern concrete.

Fig. 2: Ancient Roman structure still standing proudly after 2000 years

The goal of this study is to develop highly durable and environmentally-friendly concrete by mimicking the cementation mechanism of ancient Roman concrete and by using the raw materials readily available in the U.S.

Methodology

Nano

- Heat evolution
- Nanostructure

Micro

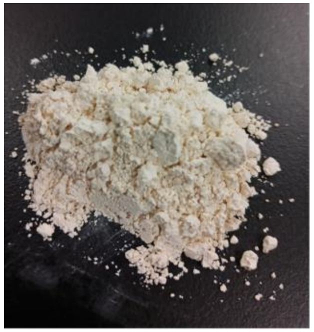
- Mineralogy of reaction products
- Portlandite consumption
- Microstructure

Macro

- Compressive strength
- Chloride and sulfate sequestration

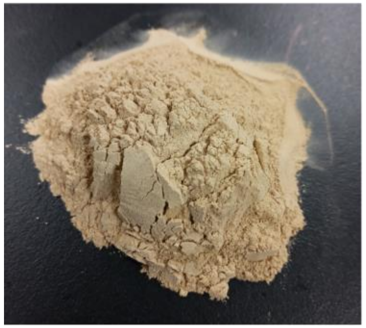
Bottom-up Approach

Sample preparation



Calcined Kaolin

Portlandite



Calcined Montmorillonite

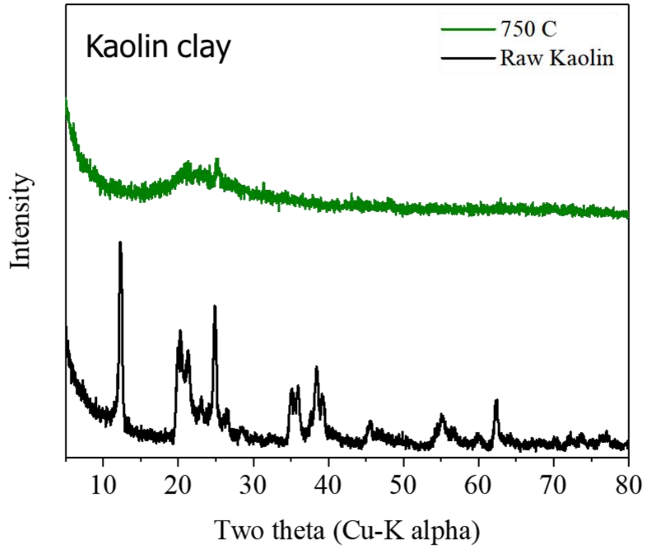
Seawater

Paste Mixer

25 mm paste cubes

Sample preparation

- Calcination temperature: 750°C
- Calcination duration: 120 min
- Water to binder ratio: 0.6
- Samples were cured in seawater at 23°C



Mix ID	Calcined kaolinite to montmorillonite ratio	Calcined clay to portlandite ratio
M1	100:0	2:1
M2	50:50	2:1
M3	75:25	2:1
M4	100:0	3:1
M5	50:50	3:1
M6	75:25	3:1
M7	100:0	4:1
M8	50:50	4:1
M9	75:25	4:1

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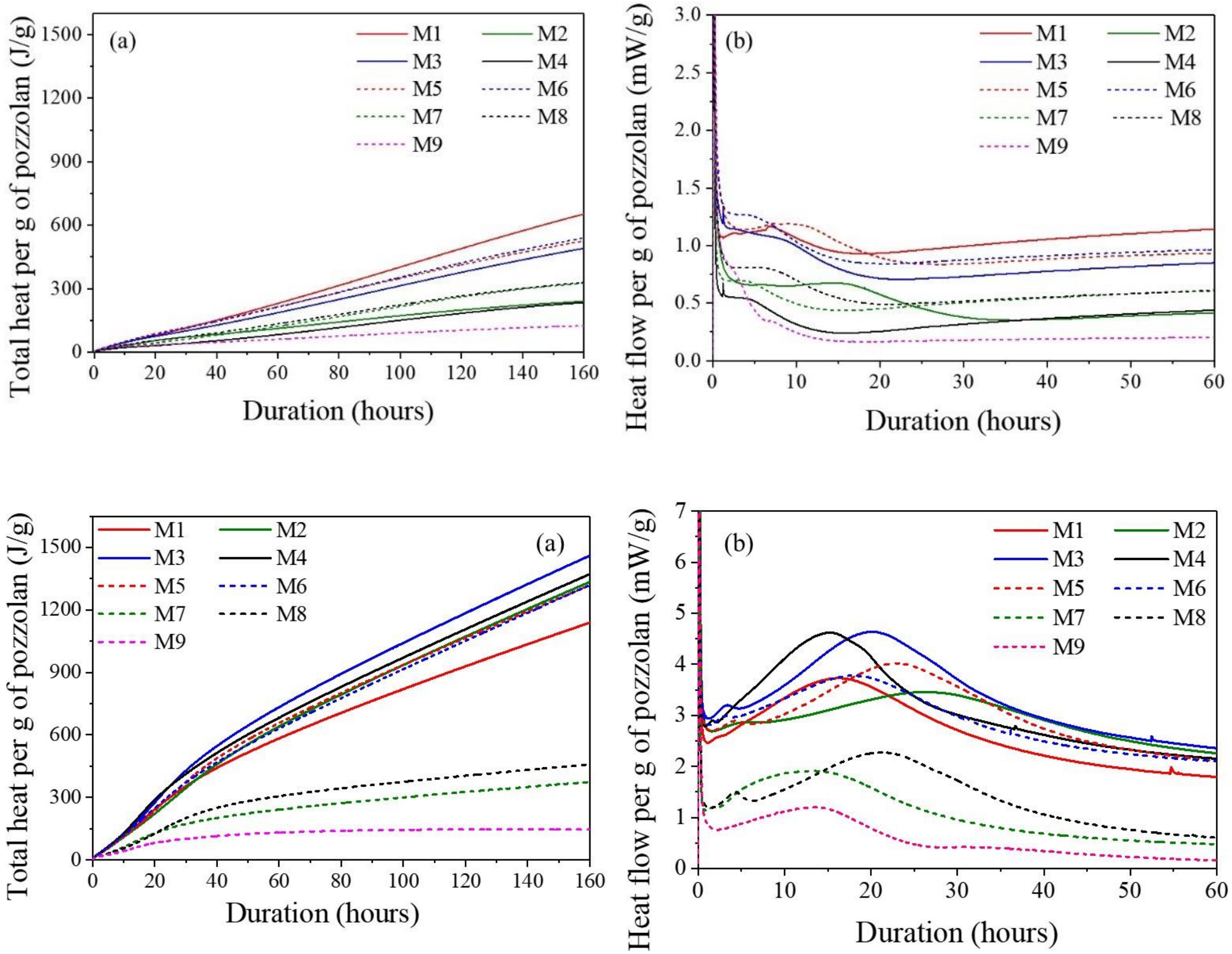
Heat of reaction

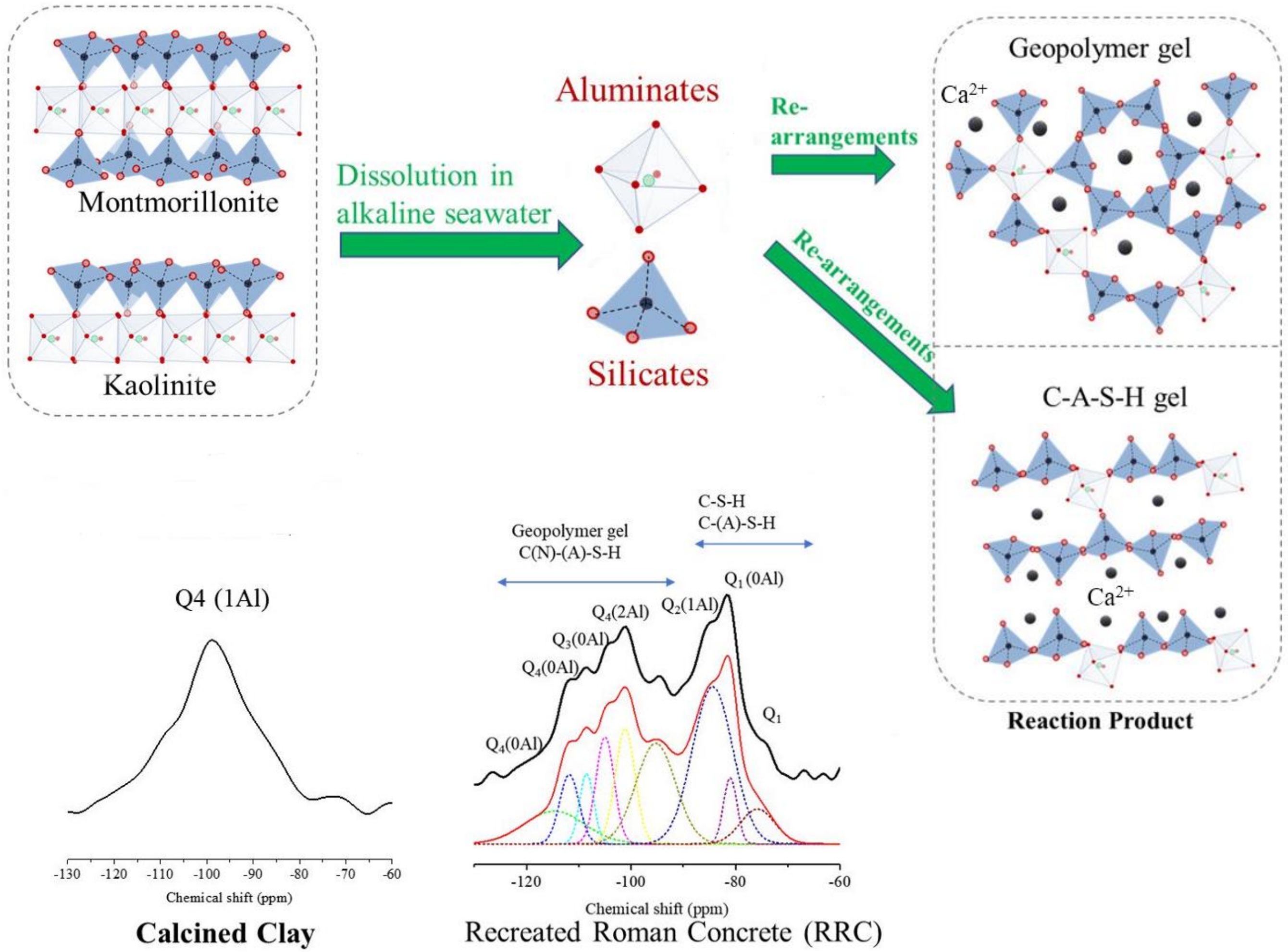
DI Water

Seawater



Alkaline seawater acts as an activator to the calcined clay-portlandite system

Nanostructure



Co-existence of C-A-S-H gel and geopolymer gel in nanostructure

ACI CONCRETE CONVENTION

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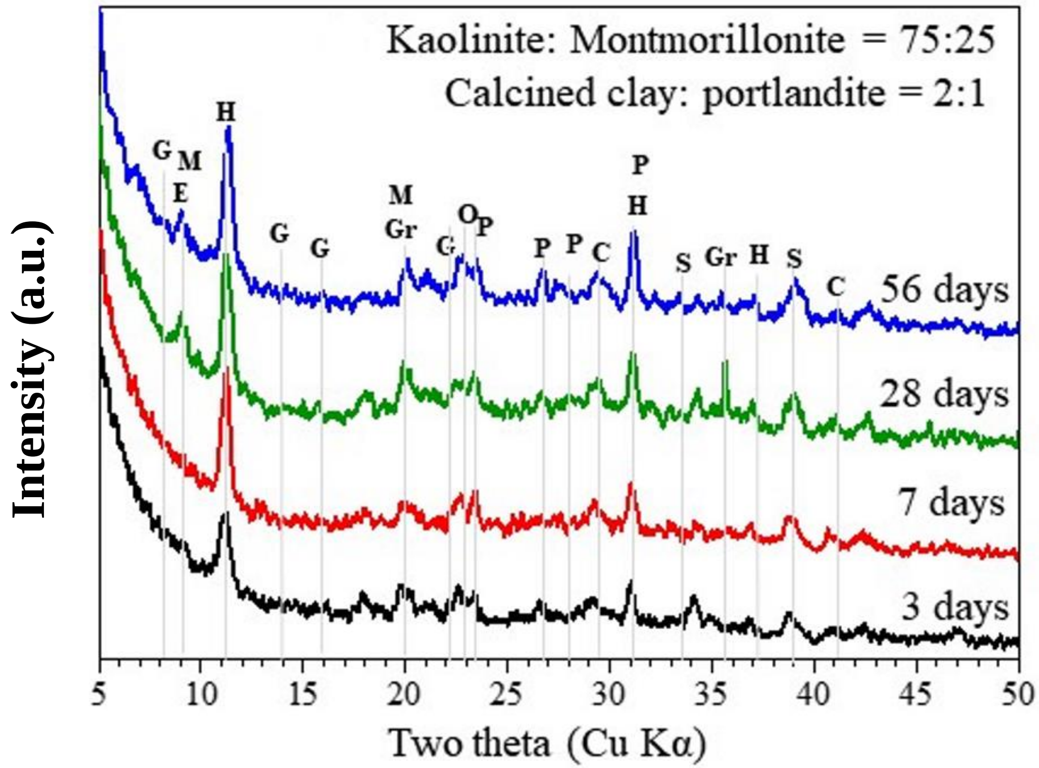
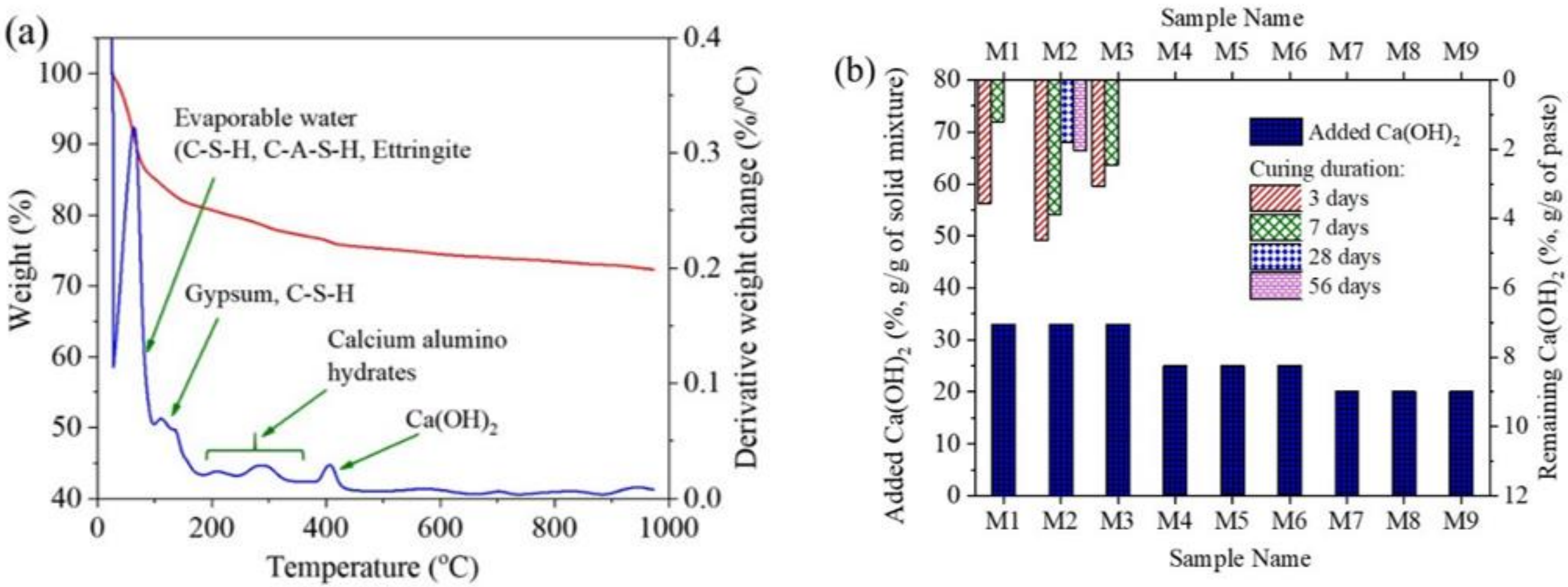
Mineralogy of reaction products



H: Hydrocalumite, PDF # 900-9354
E: Ettringite, PDF #901-2923
M: Montmorillonite
P: Phillipsite, PDF #900-9661
C: Calcium aluminum silicate hydrate (C-A-S-H)
O: Okenite, PDF #901-5623
S: Gypsum, PDF#101-1075
G: Gyrolite, PDF #900-9473
Gr: Grossite, Grossular, PDF #900-7447, #900-0626

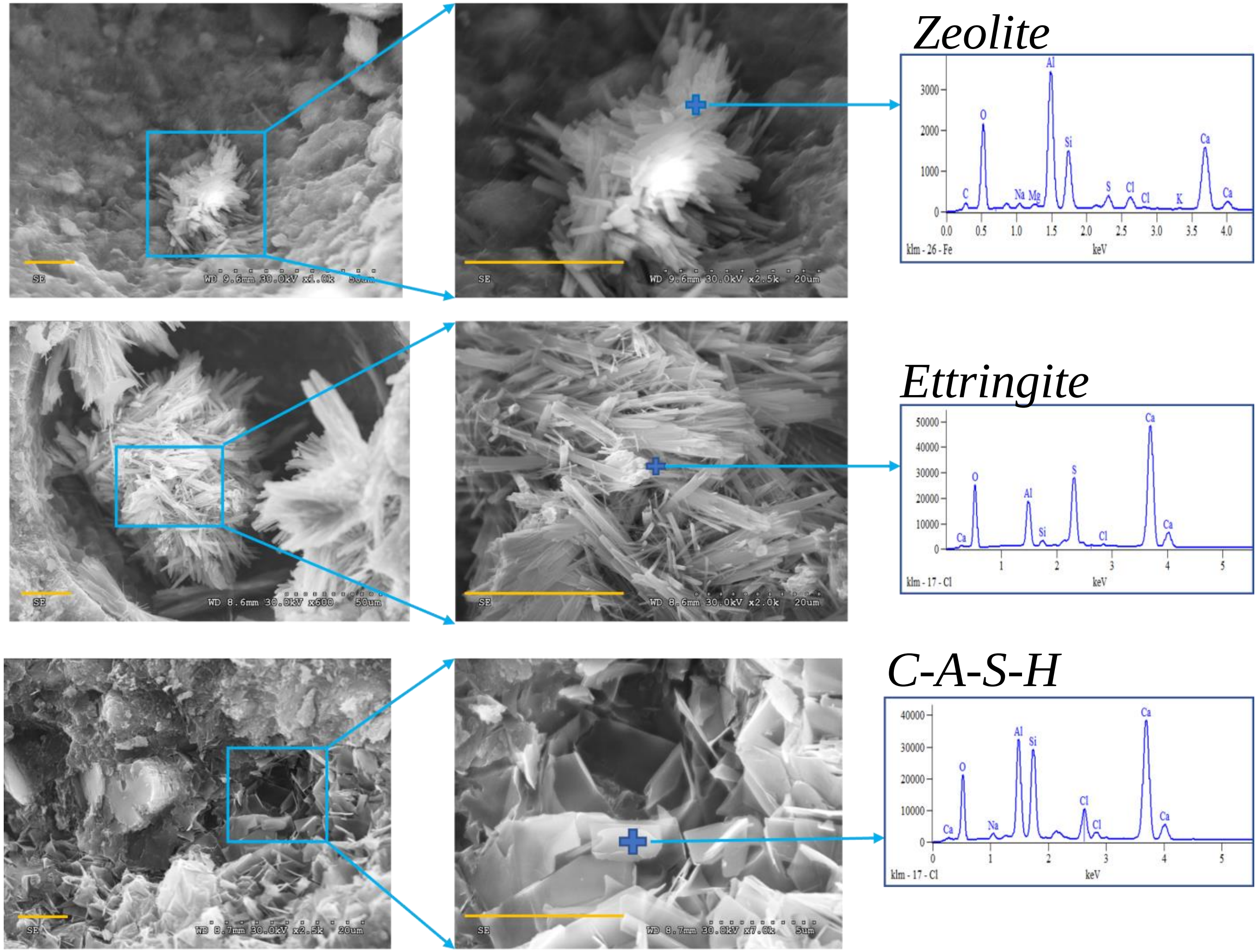
Recreated Roman Concrete (RRC) contains mineral phases similar to that of ancient Roman concrete, including phillipsite, hydrocalumite, C-A-S-H

Portlandite consumption



The more alumina is present, the faster the portlandite is consumed!

Microstructures



Primary microstructural phases observed: crystalline C-A-S-H phase, Ettringite, crystalline zeolite phase

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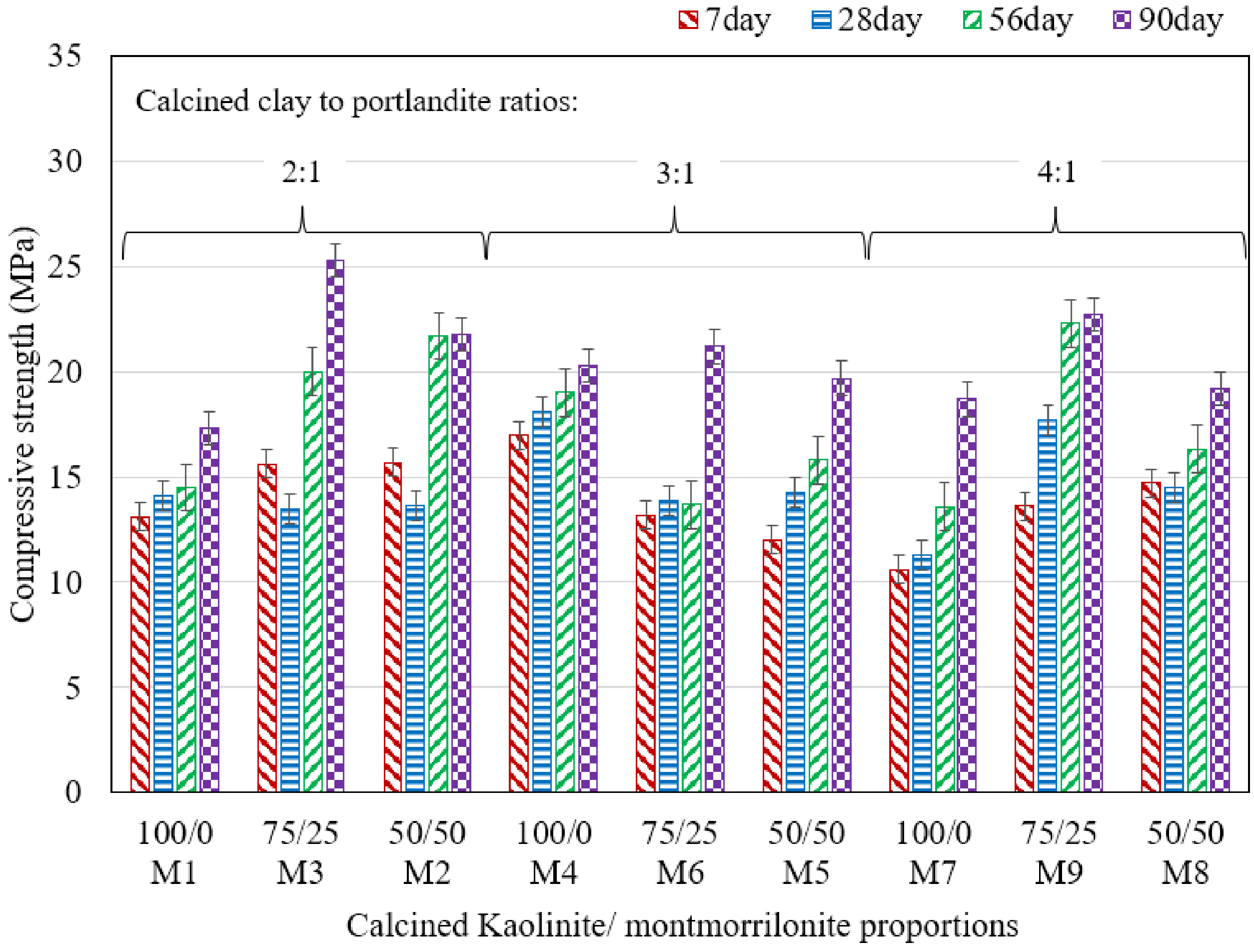
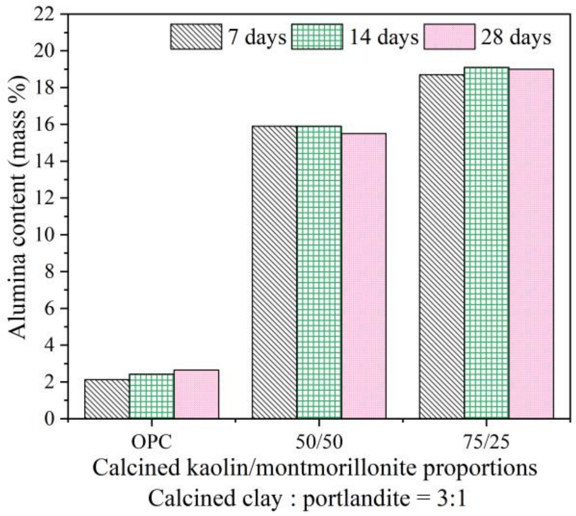
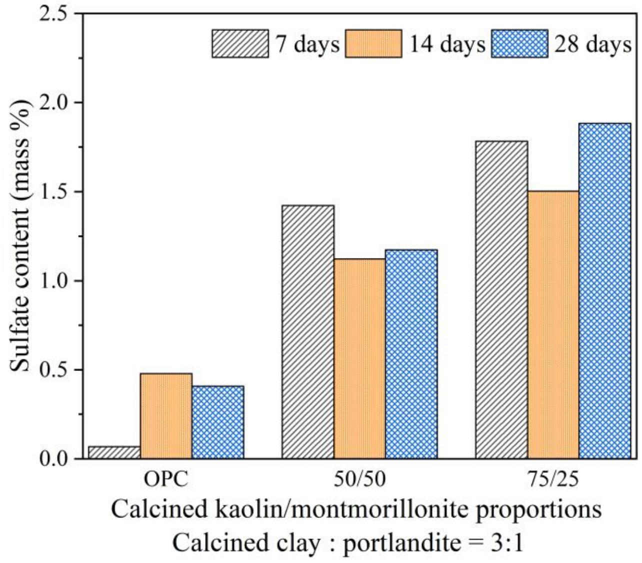
Compressive strength

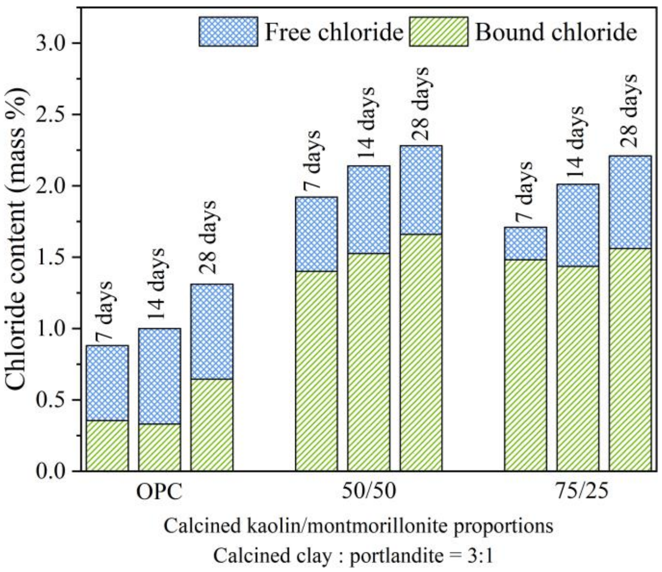


By optimizing calcined clay to portlandite ratio and water to binder ratio it is possible to achieve 30 MPa or 4000 psi strength at 28 days

Chloride and sulfate sequestration







Alumina present in the calcined clay help sequester chloride and sulfate as hydrocalumite and ettringite and hence improving the long-term performance

Summary and future direction

- Calcined clay-portlandite paste prepared with seawater showed significantly higher reactivity.

- Sequestration of ions (chlorides and sulfates) present in seawater was identified as one of the primary factors contributing to the compressive strength development of the calcined-portlandite mixtures.

The ongoing tasks are

- investigating the *environmental impacts of RRC* and its comparison with modern Portland cementitious materials
- understanding the *role of sulfate and chloride sequestration* in RRC matrixes

Thank you!

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