Evaluating the Applicability of R3-Reactivity Test (ASTM C1897) to Blended Systems

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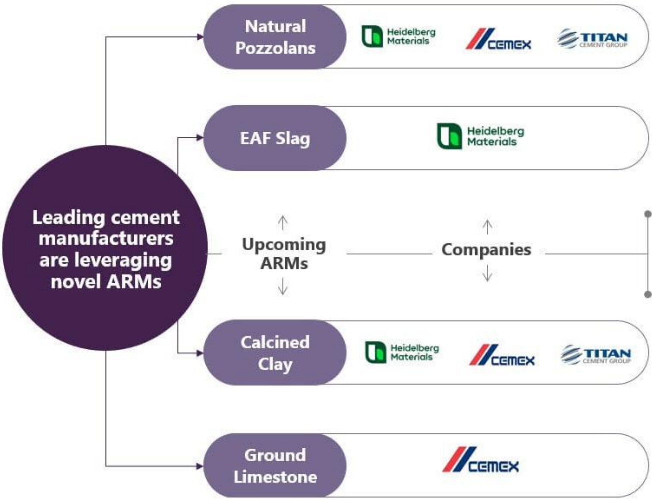
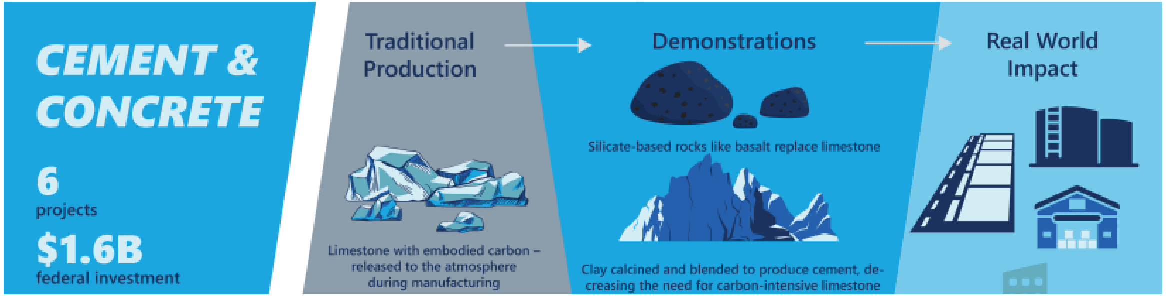
Push to Clinker Substitution

Industrial Push to Clinker Substitution



Regulatory Push to Clinker Substitution



- https://www.evalueserve.com/blog/cement-companies-accelerate-co2-reduction-with-clinker-substitution/

https://www.energy.gov/oced/industrial-demonstrations-program-selections-award-negotiations-cement-and-concrete

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EU Standards

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass[a]) — Main constituents: Clinker	Blast-furnace slag	Silica fume	Pozzolana: natural	Pozzolana: natural calcined	Fly ash: siliceous	Fly ash: calcareous	Burnt shale	Limestone	Limestone	Minor additional constituents
			K	S	D[b]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	–	–	–	–	–	–	–	–	0-5
		CEM II/B-S	65-79	21-35	–	–	–	–	–	–	–	–	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	–	6-10	–	–	–	–	–	–	–	0-5
	Portland-pozzolana cement	CEM II/A-P	80-94	–	–	6-20	–	–	–	–	–	–	0-5
		CEM II/B-P	65-79	–	–	21-35	–	–	–	–	–	–	0-5
		CEM II/A-Q	80-94	–	–	–	6-20	–	–	–	–	–	0-5
		CEM II/B-Q	65-79	–	–	–	21-35	–	–	–	–	–	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	–	–	–	–	6-20	–	–	–	–	0-5
		CEM II/B-V	65-79	–	–	–	–	21-35	–	–	–	–	0-5
		CEM II/A-W	80-94	–	–	–	–	–	6-20	–	–	–	0-5
		CEM II/B-W	65-79	–	–	–	–	–	21-35	–	–	–	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	–	–	–	–	–	–	6-20	–	–	0-5
		CEM II/B-T	65-79	–	–	–	–	–	–	21-35	–	–	0-5
	Portland-limestone cement	CEM II/A-L	80-94	–	–	–	–	–	–	–	6-20	–	0-5
		CEM II/B-L	65-79	–	–	–	–	–	–	–	21-35	–	0-5
		CEM II/A-LL	80-94	–	–	–	–	–	–	–	–	6-20	0-5
		CEM II/B-LL	65-79	–	–	–	–	–	–	–	–	21-35	0-5
	Portland-composite cement[c]	CEM II/A-M	80-88	<------ 12-20 ------>									0-5
		CEM II/B-M	65-79	<------ 21-35 ------>									0-5
CEM III	Blast furnace cement	CEM III/A	35-64	36-65	–	–	–	–	–	–	–	–	0-5
		CEM III/B	20-34	66-80	–	–	–	–	–	–	–	–	0-5
		CEM III/C	5-19	81-95	–	–	–	–	–	–	–	–	0-5
CEM IV	Pozzolanic cement[c]	CEM IV/A	65-89	–	<------ 11-35 ------>					–	–	–	0-5
		CEM IV/B	45-64	–	<------ 36-55 ------>					–	–	–	0-5
CEM V	Composite cement[c]	CEM V/A	40-64	18-30	–	<--- 18-30 --->		–	–	–	–	–	0-5
		CEM V/B	20-38	31-49	–	<--- 31-49 --->		–	–	–	–	–	0-5

Main types	Notation of the products (types of common cement): Name	Abbreviation	Composition (percentage by mass[a]) — Main constituents: Clinker	Blast-furnace slag	Silica fume	Pozzolana: natural	Pozzolana: natural calcined	Fly ash: siliceous	Fly ash: calcareous	Burnt shale	Limestone	Limestone	Minor additional constituents
			K	S	D[b]	P	Q	V	W	T	L[c]	LL[c]	
CEM II	Portland-composite	CEM II/C-M	50-64	<------ 36-50 ------>									0-5
CEM VI	Composite cement	CEM VI (S-P)	35-49	31-59	–	6-20	–	–	–	–	–	–	0-5
		CEM VI (S-V)	35-49	31-59	–	–	–	6-20	–	–	–	–	0-5
		CEM VI (S-L)	35-49	31-59	–	–	–	–	–	–	6-20	–	0-5
		CEM VI (S-LL)	35-49	31-59	–	–	–	–	–	–	–	6-20	0-5

LC³

RCF

Main types	Notation of the products (types of cement): Type name	Type notation	Composition (percentage by mass)[a] — Main constituents: Clinker	Recycled concrete fines	Blast-furnace slag	Silica fume	Pozzolana: natural	Pozzolana: natural calcined	Fly ash: siliceous	Fly ash: calcareous	Burnt shale	Limestone	Limestone	Minor additional constituents
			K	F	S	D[b]	P	Q	V	W	T	L[c]	LL[c]	
CEM II	Portland-recycled-fines cement	CEM II/A-F	80–94	6–20	—	—	—	—	—	—	—	—	—	0–5
	Portland-composite cement[d]	CEM II/A-M	80–88	6–14	<------ 6–14 ------>									0–5
		CEM II/B-M	65–79	6–20	<------ 6–29 ------>									0–5
		CEM II/C-M	50–64	6–20	<------ 16–44 ------>									0–5

27 common cement types + many more upcoming cements

EN 197-1:2000

EN 197-5:2021
EN 197-6: 2023

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Reactivity of Binder

Existing & Upcoming Cement Blends

Diversification of Cement Composition

Increase in the **Clinker Replacement** in a Given Blend

Reactivity of SCMs

Mechanical

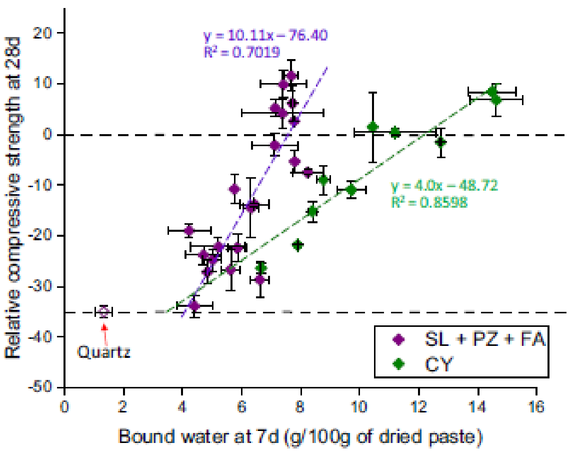
Durability

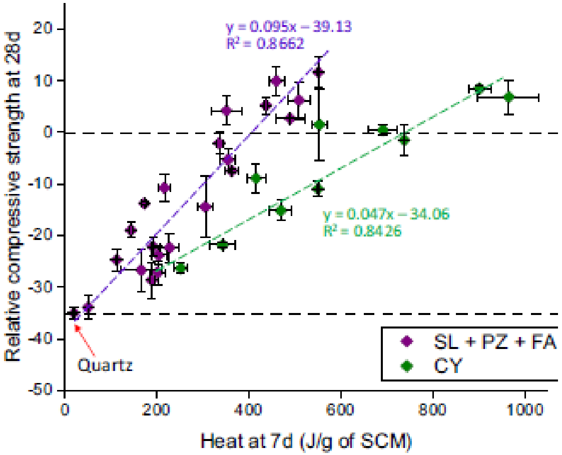
My PhD Thesis area!

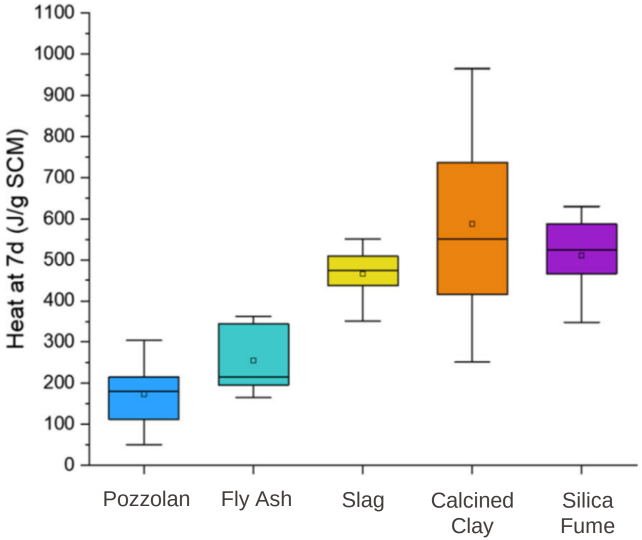
R3-Reactivity Test (ASTM C1897)

R3 is a successful technique to measure the reactivity of **individual** SCMs

Ingredient	SCM	Calcium Hydroxide	Calcium Carbonate	Potassium solution
Mass (g)	10	30	5	54







Londono-Zuluaga, D., Gholizadeh-Vayghan, A., Winnefeld, F. *et al.* Report of RILEM TC 267-TRM phase 3: validation of the R³ reactivity test across a wide range of materials. *Mater Struct* **55**, 142 (2022). https://doi.org/10.1617/s11527-022-01947-3

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Problem Statement

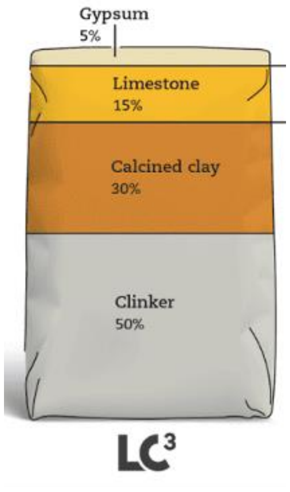
Ingredient	SCM	Calcium Hydroxide	Calcium Carbonate	Potassium solution
Mass (g)	10	30	5	54

Can we test the intrinsic reactivity of blends instead of individual SCMs?

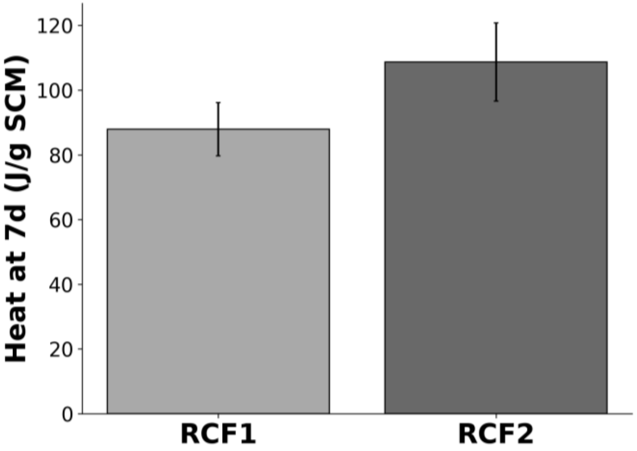
Experimental Plan: Materials

LC^3-50

Limestone

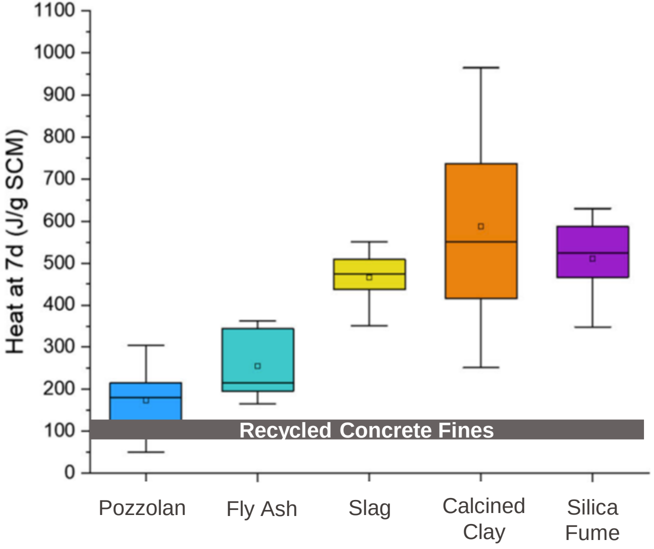


Recycled Concrete Fines (RCF)



RC^3-50

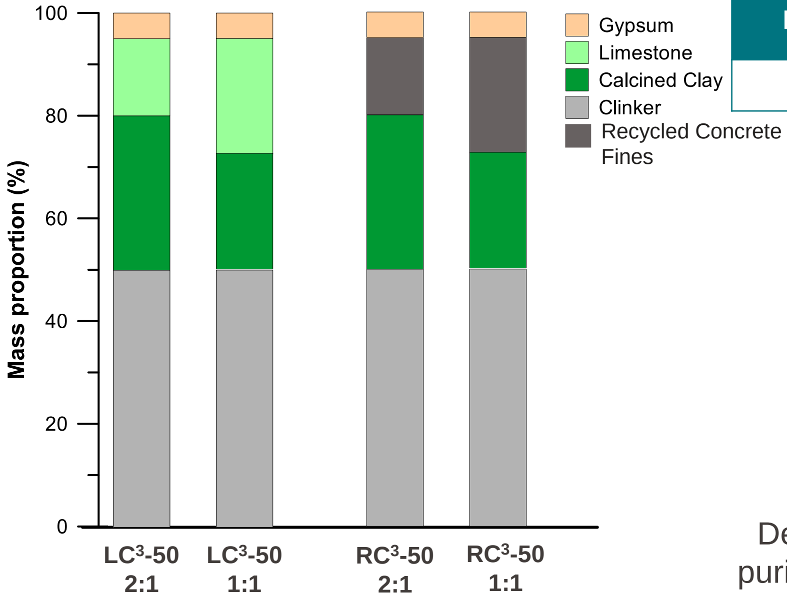
Recycled Concrete Fines (RCF)



- *Image from LC3 Project*

Londono-Zuluaga et al. (2022). Report of RILEM TC 267-TRM phase 3: validation of the R^3 reactivity test across a wide range of materials.

Experimental Plan: Materials



2:1 Blends, 1:1 Blends — Calcined Clay:Filler

Ingredient	SCM	Calcium Hydroxide	Calcium Carbonate	Potassium solution
Mass (g)	10	30	5	54

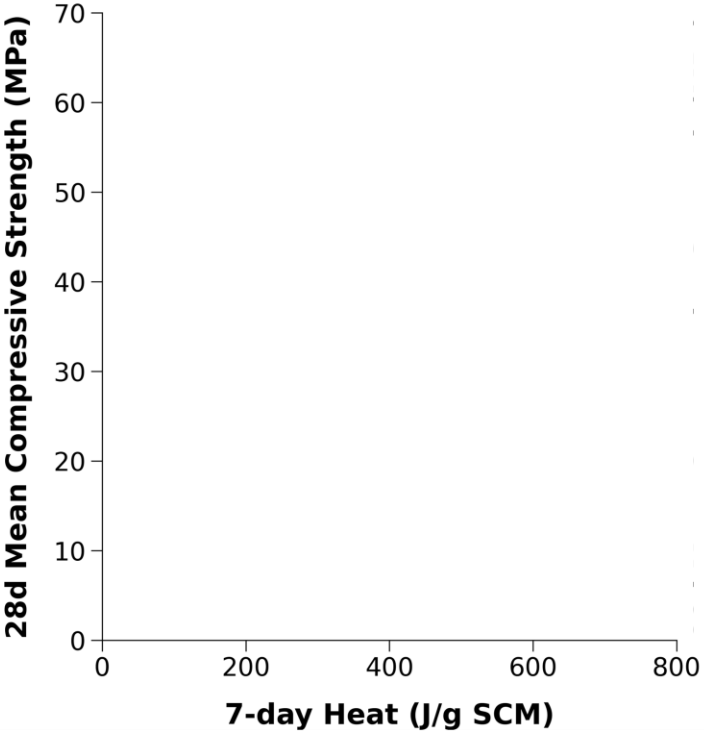
SCM: 2:1 Blends, 1:1 Blends — Calcined Clay:Filler

Decrease in purity (Kaol.%) ↓

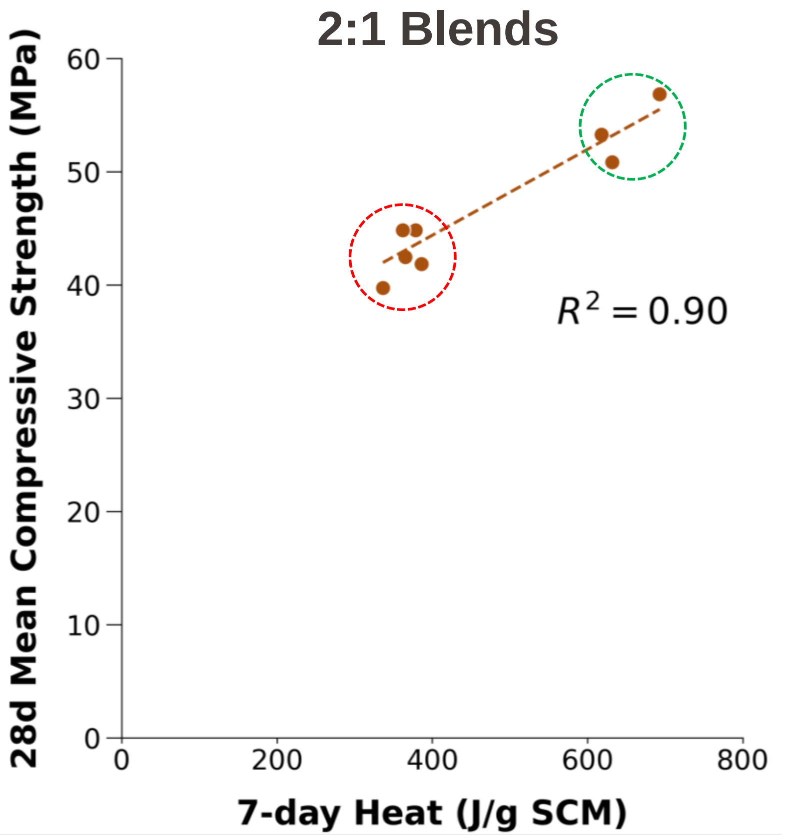
Calcined Clay (C)	Filler (F)
C1 (95% Kaol.)	Limestone (F1)
C2 (50% Kaol.)	RCF1 (F2)
C3 (40% Kaol.)	RCF2 (F3)

In total, 18 mixes were tested for R3-reactivity and mortar compressive strength

Results: 7d R3-heat vs compressive strength



Results: 7d R3-heat vs compressive strength



- **Kaolinite content** of the clay dependent
- Characterization of the **'strength potential'** of blends
- **Primary Screening** of blended systems

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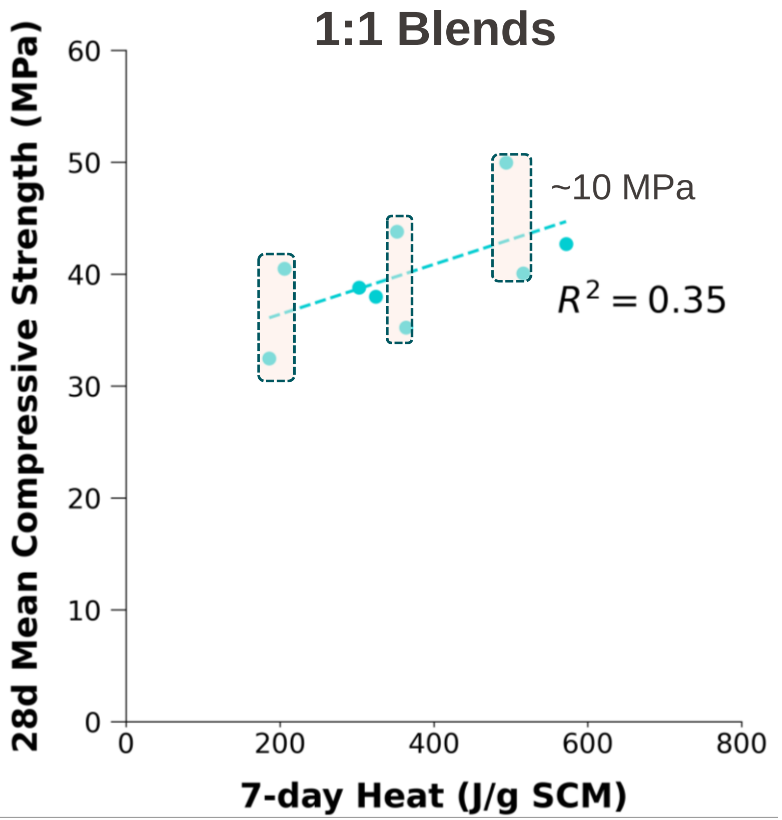
Results: 7d R3-heat vs compressive strength



- **~10 MPa** variation in strength for similar 7d R3-heat values
- Higher **filler** content leads to poor correlation
- The variability could be explained by **microstructural characterization**
  - Aluminate phases are responsible for rapid heat evolution while their contribution to hydration products is less compared to silicate phases
  - Intrinsic variability of RCFs could also play a role

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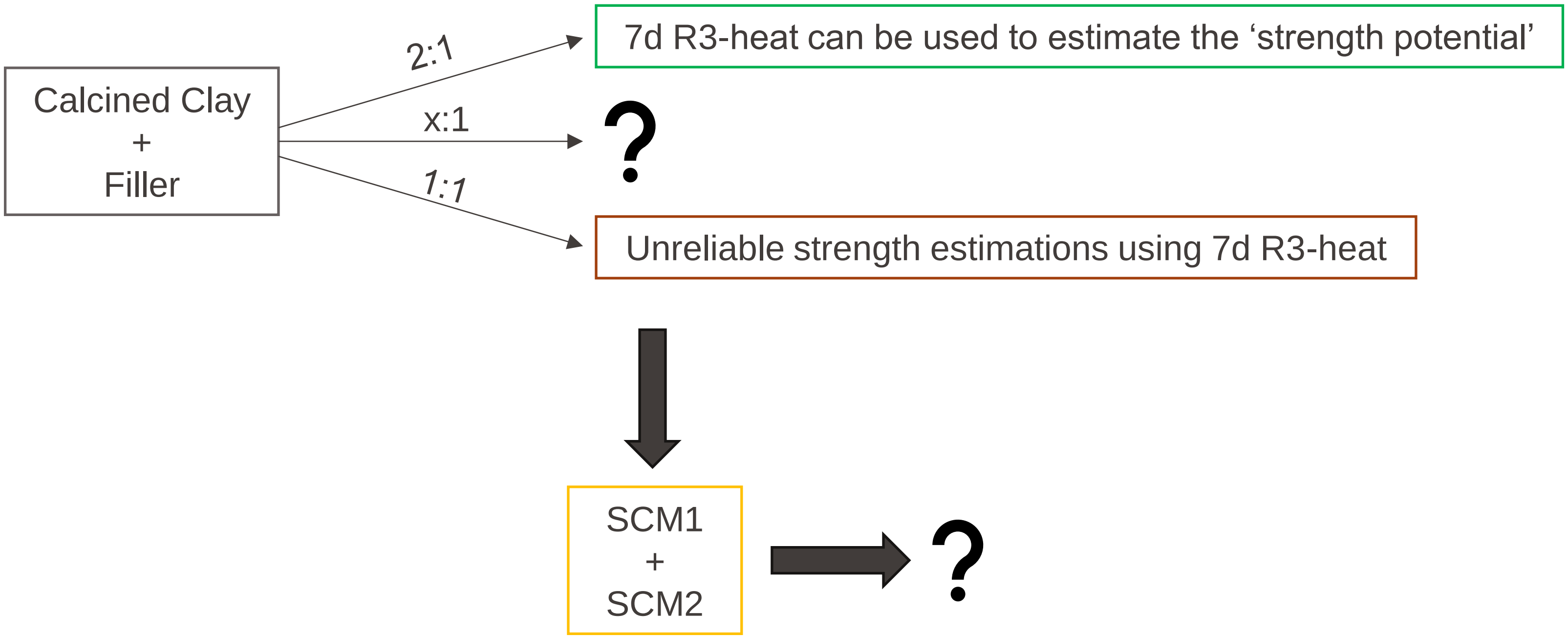
Future Plan

- Study of evolution of phase assemblage of the given mixes under R3-test conditions
- Identification of the microstructural aspects responsible for variable strength of the given mixes
- Extension of the study to other traditional and novel blended systems

Conclusions



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DETOCS

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