ConPaveStruc 2023
29 & 30 AUGUST 2023 www.cemcon-sa.org.za/conpavestruc2023

Developments in low carbon cements – a South African perspective

Emeritus Prof. Mark Alexander (UCT)

Dr Emmanuel S. Leo (UDSM)

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD
CoMSIRU

Outline

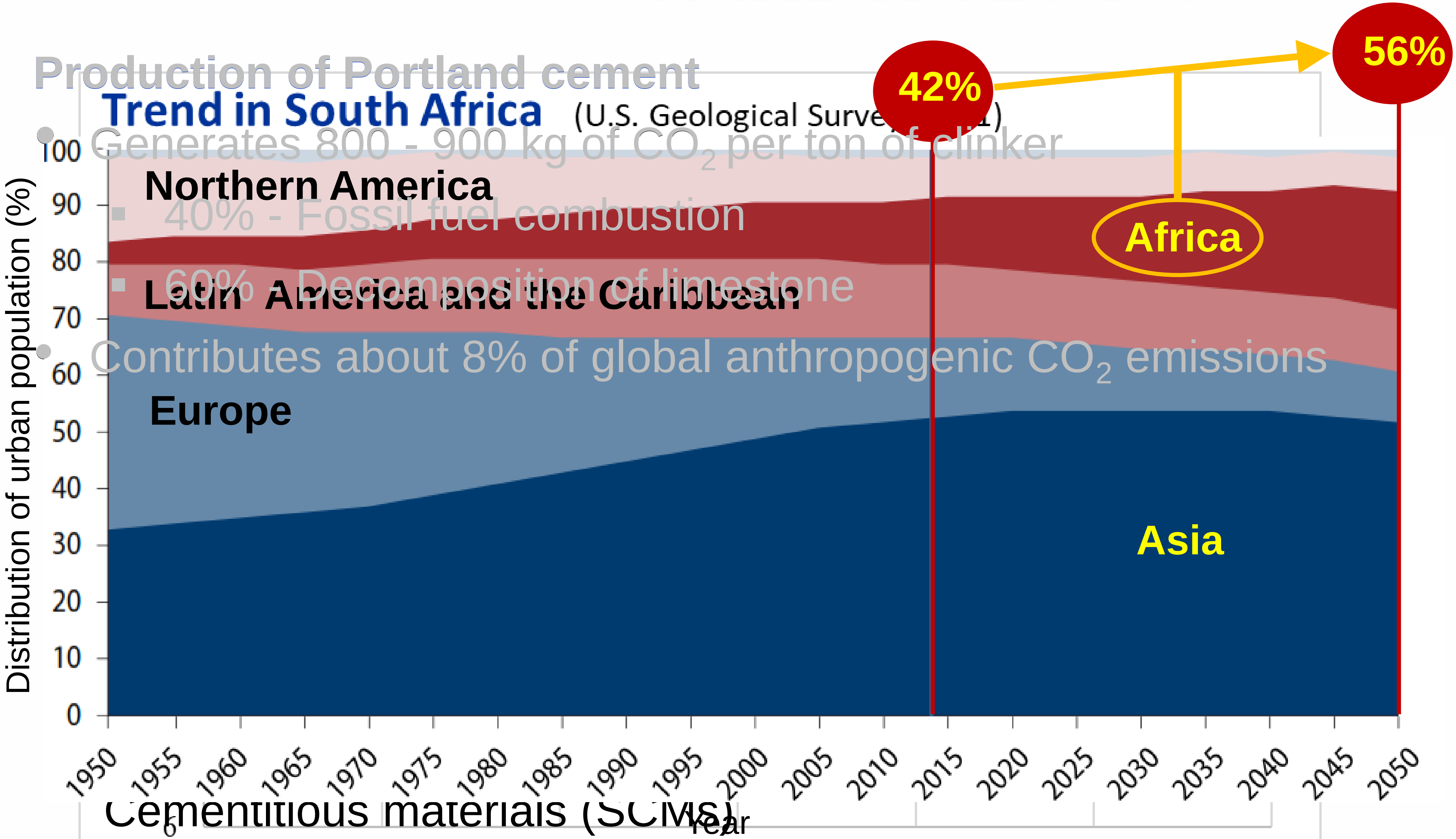
1. Production of cement
2. What is LC^3 and why we need it
3. Selected samples of kaolinite clays
4. Selected samples – Characterisation results
5. Clinker replacement (Optimisation results)
6. Concrete work
7. Conclusion

Production of Portland cement

Trend in South Africa (U.S. Geological Surve... 1)

- Generates 800 - 900 kg of CO_2 per ton of clinker
  - 40% - Fossil fuel combustion
  - 60% - Decomposition of limestone
- Contributes about 8% of global anthropogenic CO_2 emissions

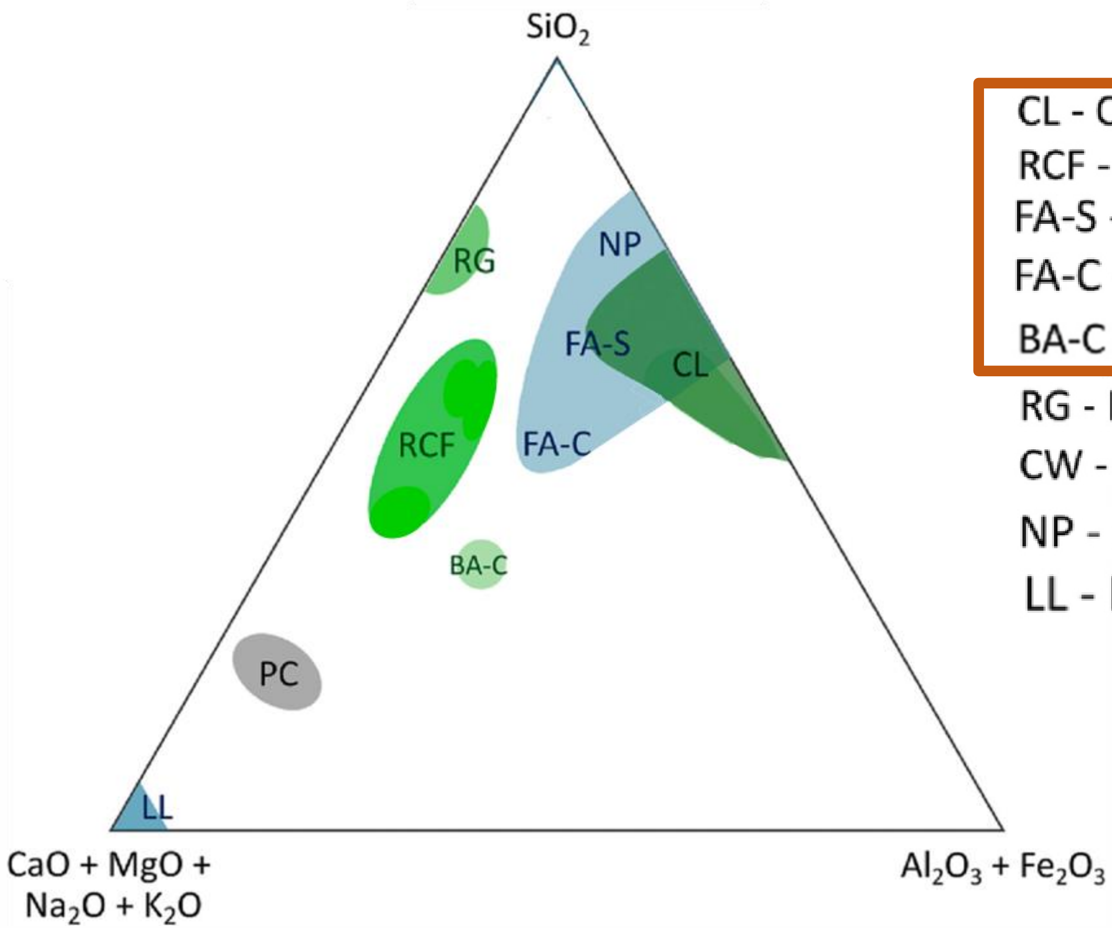
Cementitious materials (SCMs)



Distribution of urban population – Global trend

(UN report 2014, *World Urbanization Prospects*)

The chemical composition ranges of common and emerging SCMs

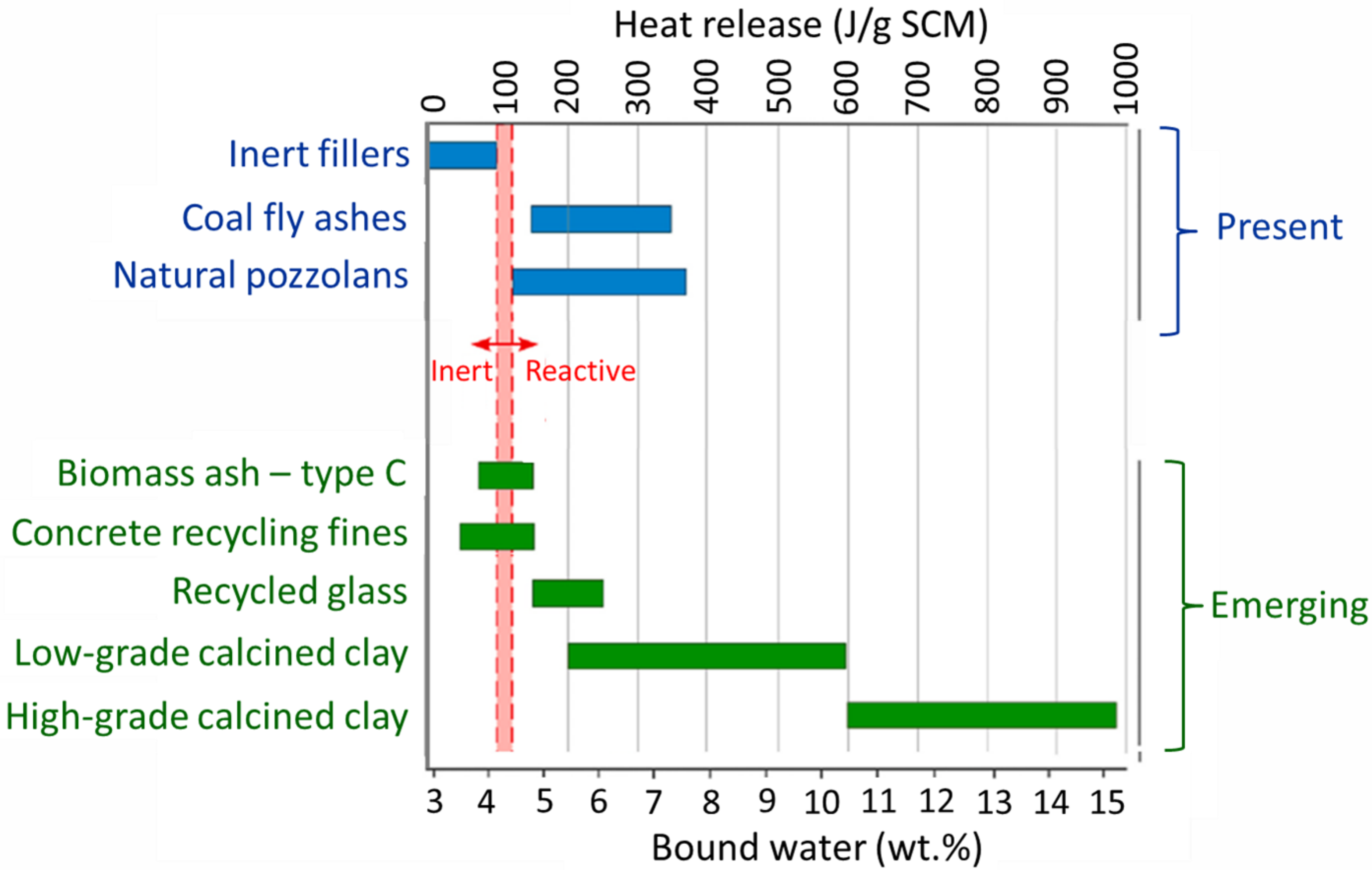


CL - Calcined clay
RCF - Recycled concrete fines
FA-S - Siliceous coal fly ash
FA-C - Calcareous coal fly ash
BA-C - Biomass ash type C

RG - Recycled glass
CW - Ceramic waste
NP - Natural pozzolan
LL - Limestone filler

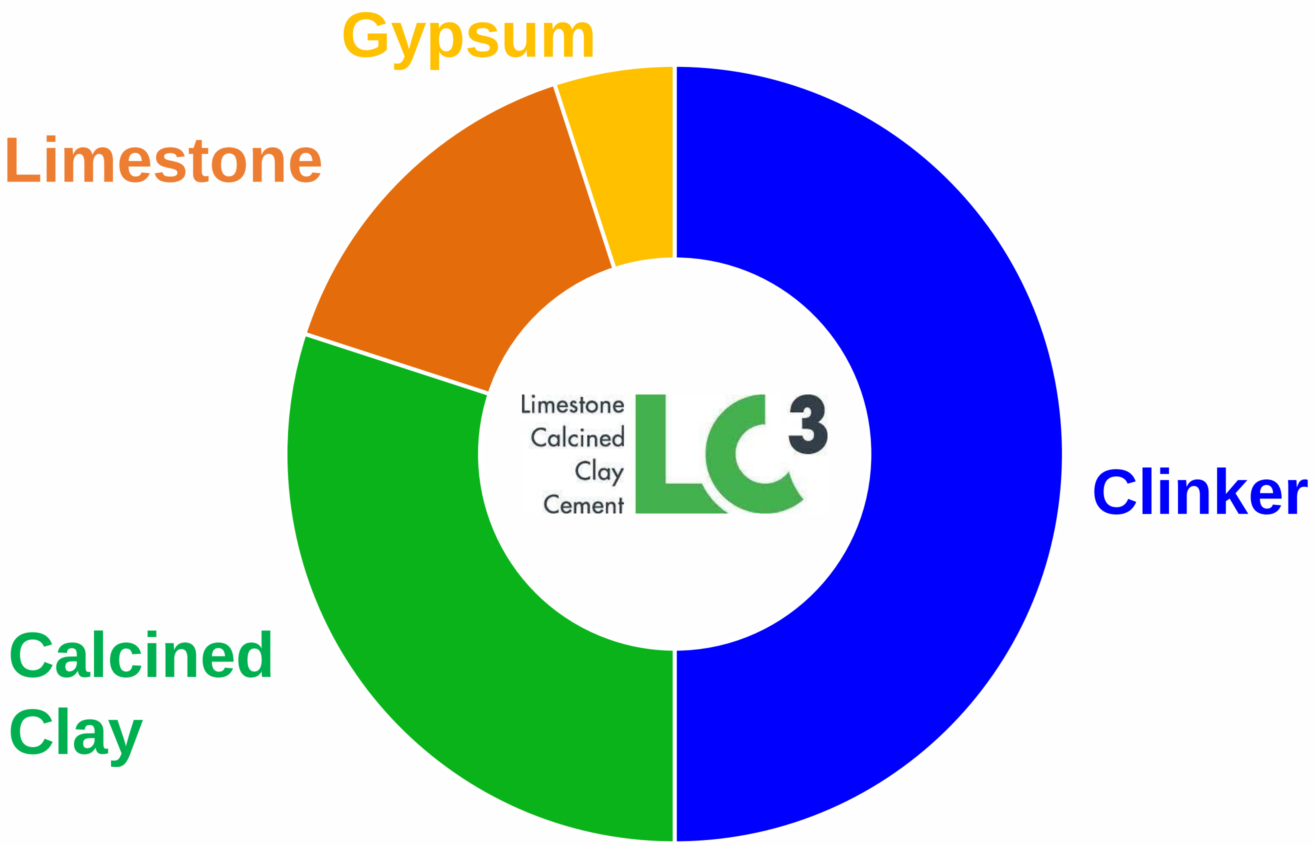
Snellings, R., Suraneni, P. and Skibsted, J., 2023. Future and emerging supplementary cementitious materials. *Cement and concrete research*, *171*, p.107199.

Reactivity levels for presently used inert fillers and common/emerging SCMs



Snellings, R., Suraneni, P. and Skibsted, J., 2023. Future and emerging supplementary cementitious materials. *Cement and concrete research*, *171*, p.107199.

What is LC³?


Gypsum
Limestone
Clinker
Calcined Clay
Limestone
Calcined
Clay
Cement
LC3

Why LC³ system

- **Slag and f... ...ries**

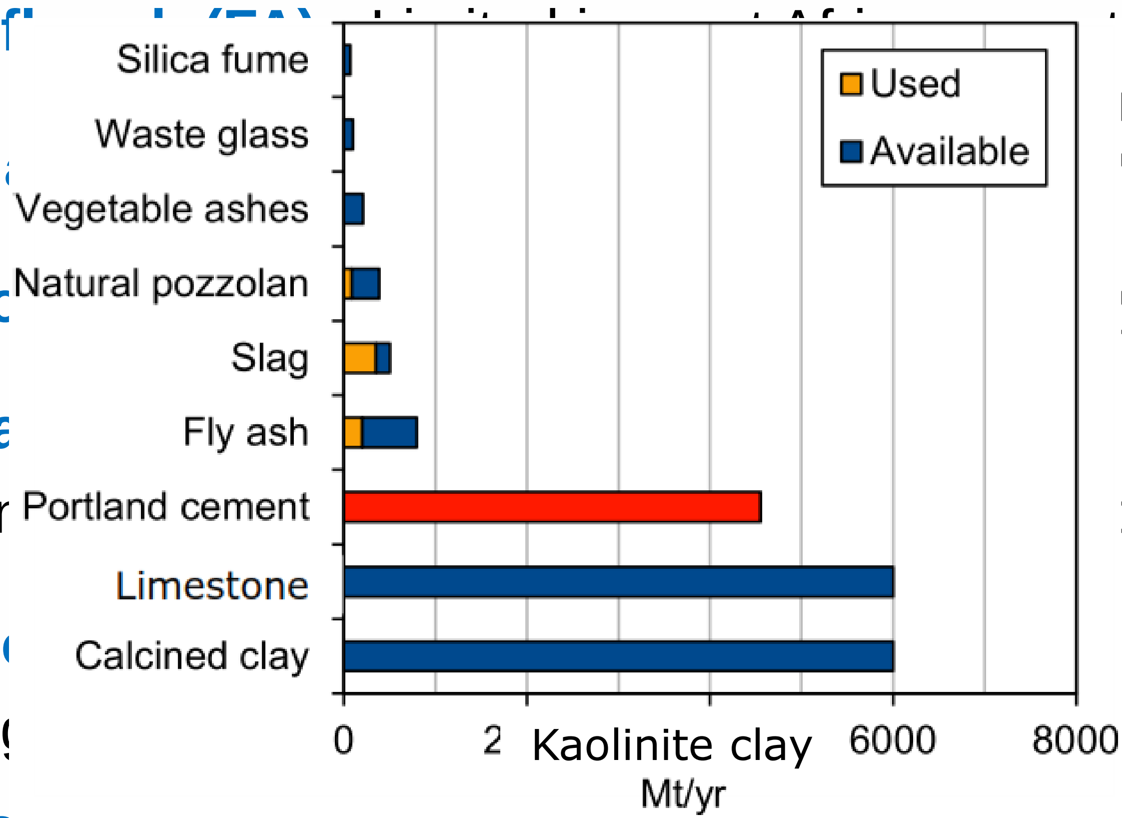
  Note: FA – ... nalanga.

  Slag ... N Cape.

- **Sources c... ...y)**

- **Energy sa...**
  - Calcir... ...of clinker

- **Calcined ...**
  - Strong...



- **Can reduce a great amount of CO_2 emissions (≈ 30%)**

$$\underbrace{AS_2H_2}_{\text{Kaolinite}} \xrightarrow[\text{Heat}]{800°C} \underbrace{AS_2}_{\text{Metakaolin}} + 2H$$

Estimated availability of SCMs versus amount of cement pr
(UNEP report on eco-efficient cements, 2016)

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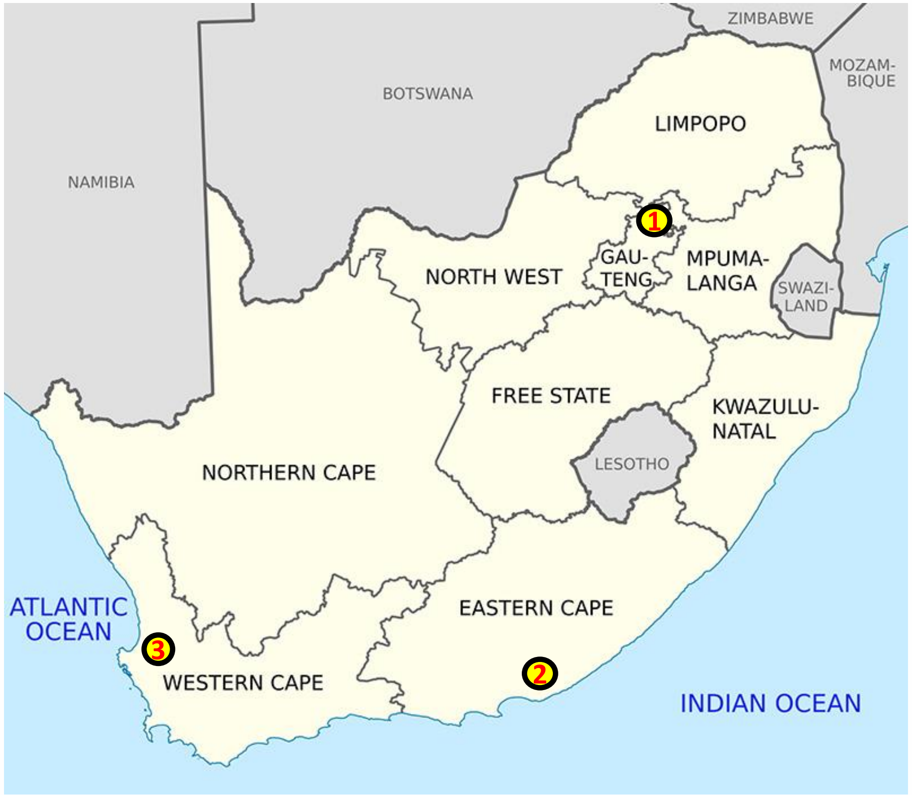
Selected kaolinite clay deposits in South Africa



1. Bronkhorstspruit
   (B-Clay)
   (35 Million tons)
2. Grahamstown
   (G-Clay)
   (60 Million tons)
3. Hopefield
   (H-Clay)
   (1 Billion tons)

4)

(Hosterman, Patterson & Good 1978; Cole, Ngcofe & Halenyane 2014; Hagemann, S)

Uncalcined samples of clay

B-Clay

PH-Clay

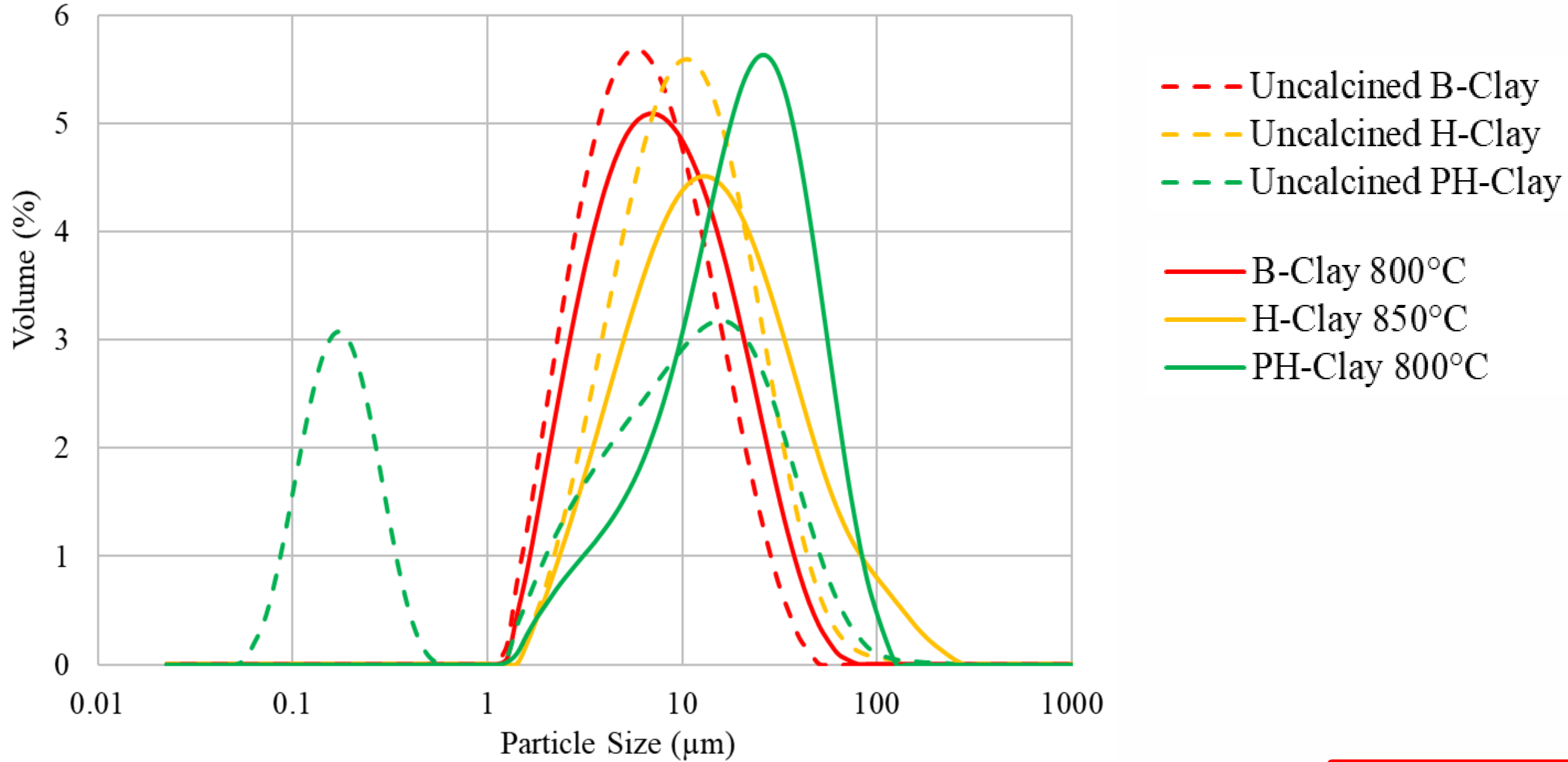
H-Clay

PH-Clay: ‘Pugu Hard’
(Dar es Salaam, Tanzania)
Included as a comparison

Selected Clays – Characteristics (Summary)

	Al_2O_3 (%)	$\frac{Al_2O_3}{SiO_2}$	LOI (%)	Na_2O_{eq} (%)	Main Phases	Kaolinite content (%)		Comment	Optimum calcination temp. (°C)
Suitable clay (Scrivener, K)	>18	>0.3	>7			**>40%**			
						TGA	**XRD**		
	(Díaz et al. 2018)					(Alujas et al. 2015)			
B-Clay	31.6	0.61	11.0	0.48	Kaolinite	68	72	**OK**	**800**
H-Clay	21.0	0.33	8.3	2.41	Illite	40	46	**OK**	**800**
PH-Clay	20.1	0.30	8.3	0.21	Quartz	49	49	**OK**	**800**

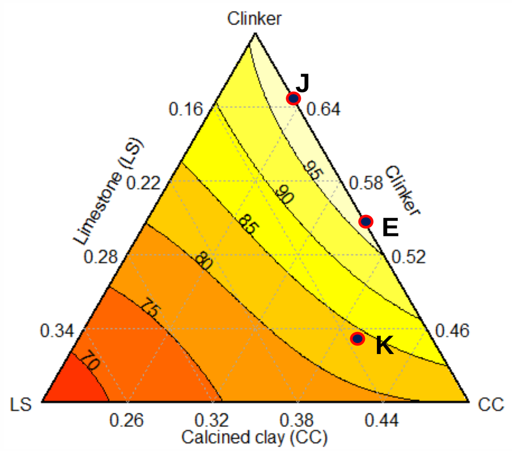
Selected clays – PSD and BET surface area



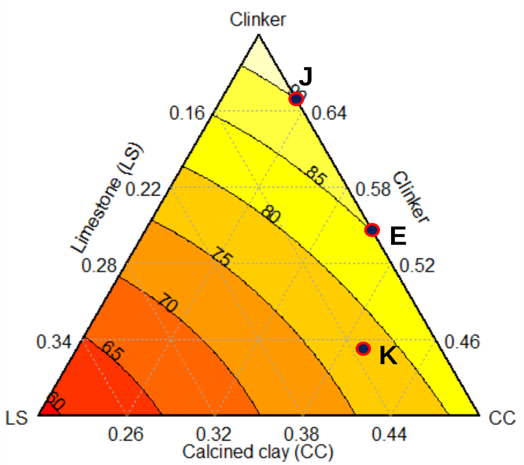
Sample Name	PSD values						BET Surface area (m^2/g)	
	d_{10} (µm)		d_{50} (µm)		d_{90} (µm)			
	Uncalcined	Calcined	Uncalcined	Calcined	Uncalcined	Calcined	Uncalcined	Calcined
B-Clay	2.3	2.6	5.9	7.1	16.5	21.4	12.6	11.1
H-Clay	3.5	3.8	9.6	12.9	26.0	49.2	5.4	4.6
PH-Clay	< 1.0	5.0	5.9	19.7	29.2	49.5	14.4	14.5

Optimisation results – 28 days mortar strengths

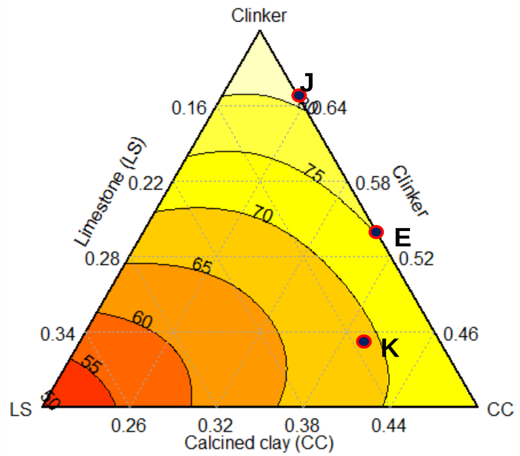
B-Clay
SO_3 = 1.8%
Na_2O_{eq} = 0.7%



PH-Clay
SO_3 = 2%
Na_2O_{eq} = 0.7%



H-Clay
SO_3 = 1.2%



	Clinker	CC	LS
E	55%	35%	10%
J	65%	25%	10%
K	45%	40%	15%

Concrete mixes

- **Three LC³ mixes**

	Clinker	CC	LS
1	55%	35%	10%
2	65%	25%	10%
3	45%	40%	15%

- **Two reference mixes**
  1. 100% CEM II/A-L 52.5N (R1)
  2. 50% CEM II + 50% GGBS (R2)

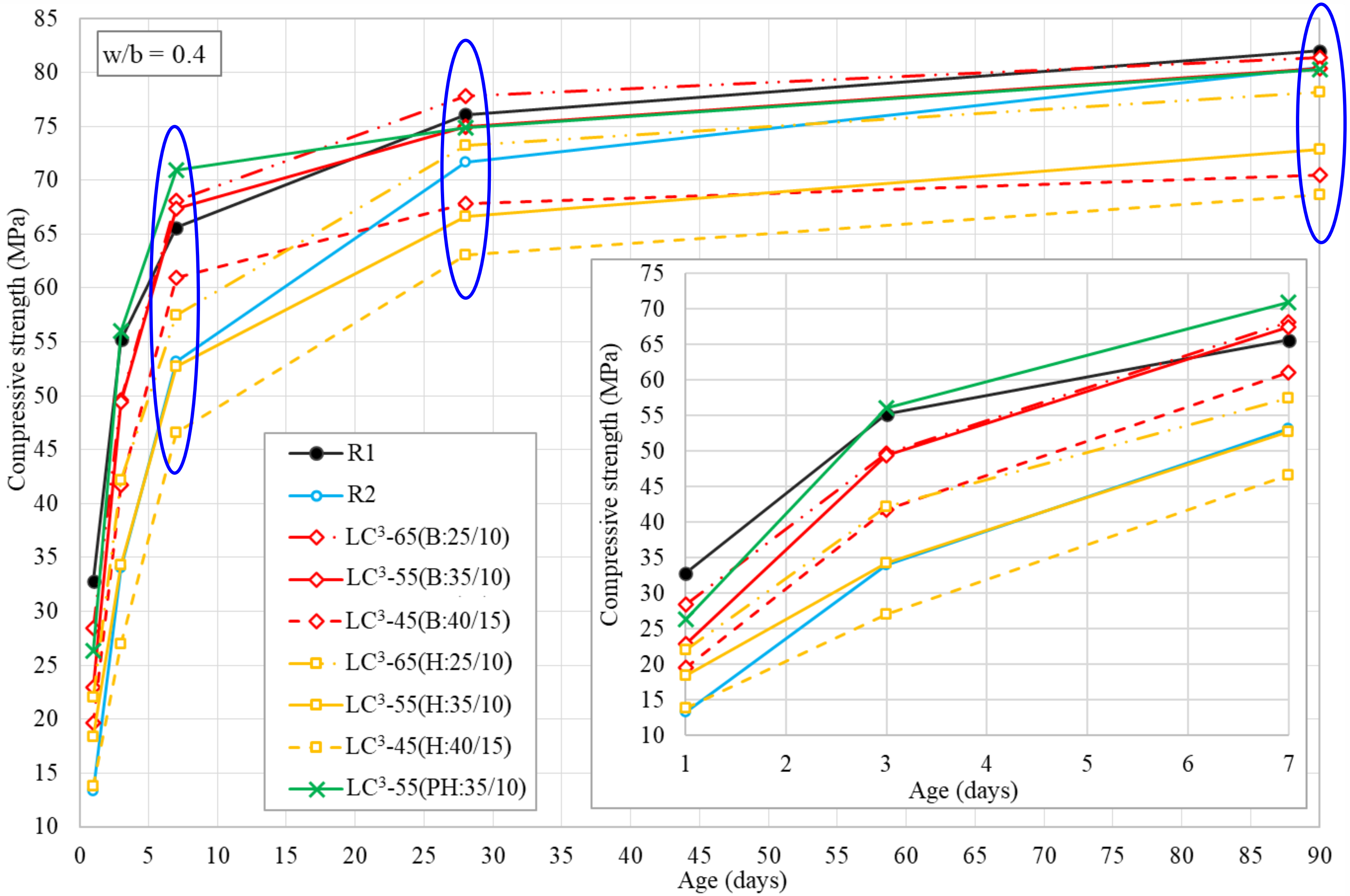
- **Two w/b :** 0.4 and 0.55

- **Sand** (Dune/Crusher: 50/50):
  0.4 w/b mixes : 842 – 866 kg/m³
  0.55 w/b mixes : 949 – 964 kg/m³

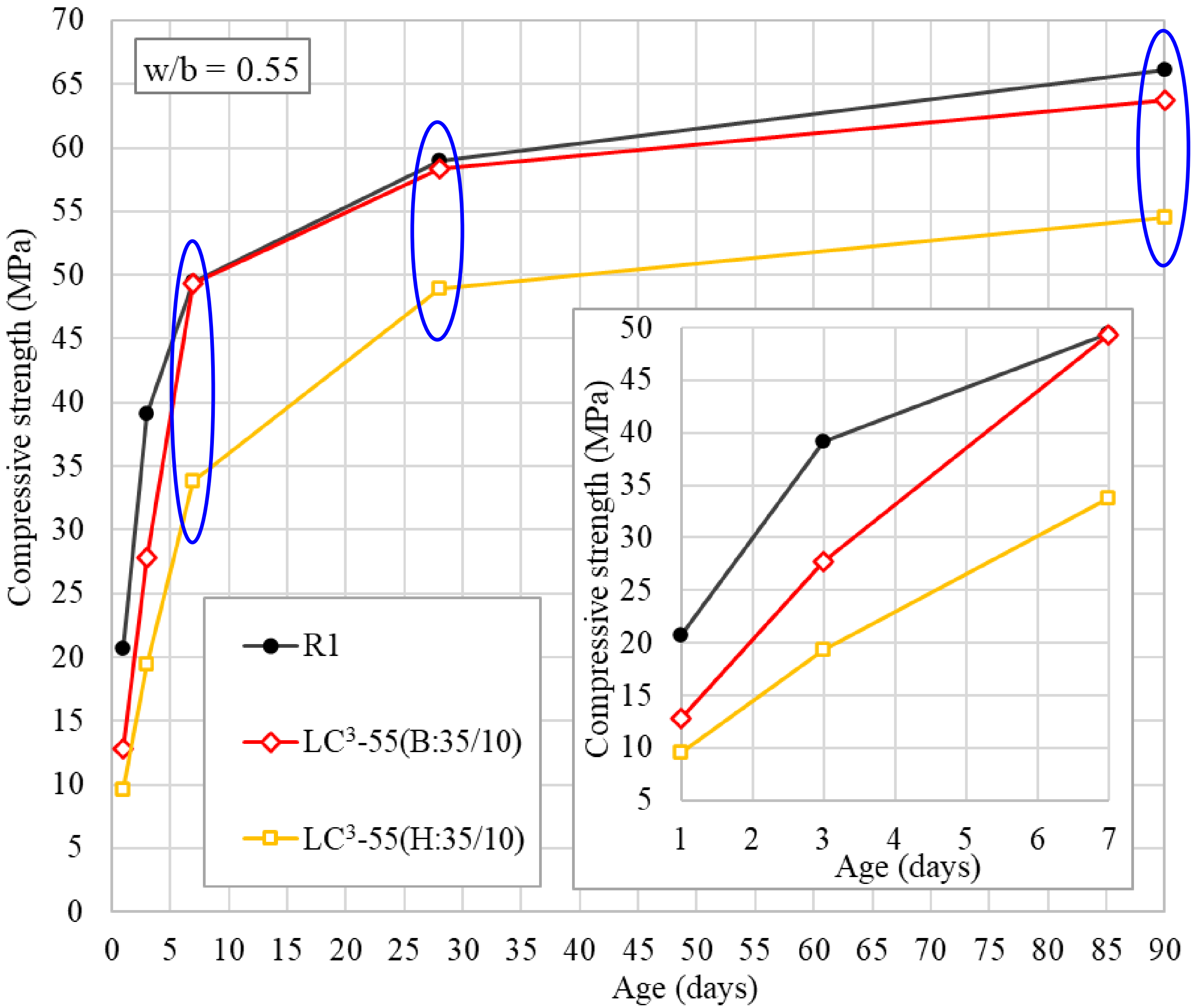
- **Stone:** 1000 kg/m³
- **Water:** 160 kg/m³

- **Superplasticizer** (Chryso® Optima 175) – **Slump:** 80 – 120 mm

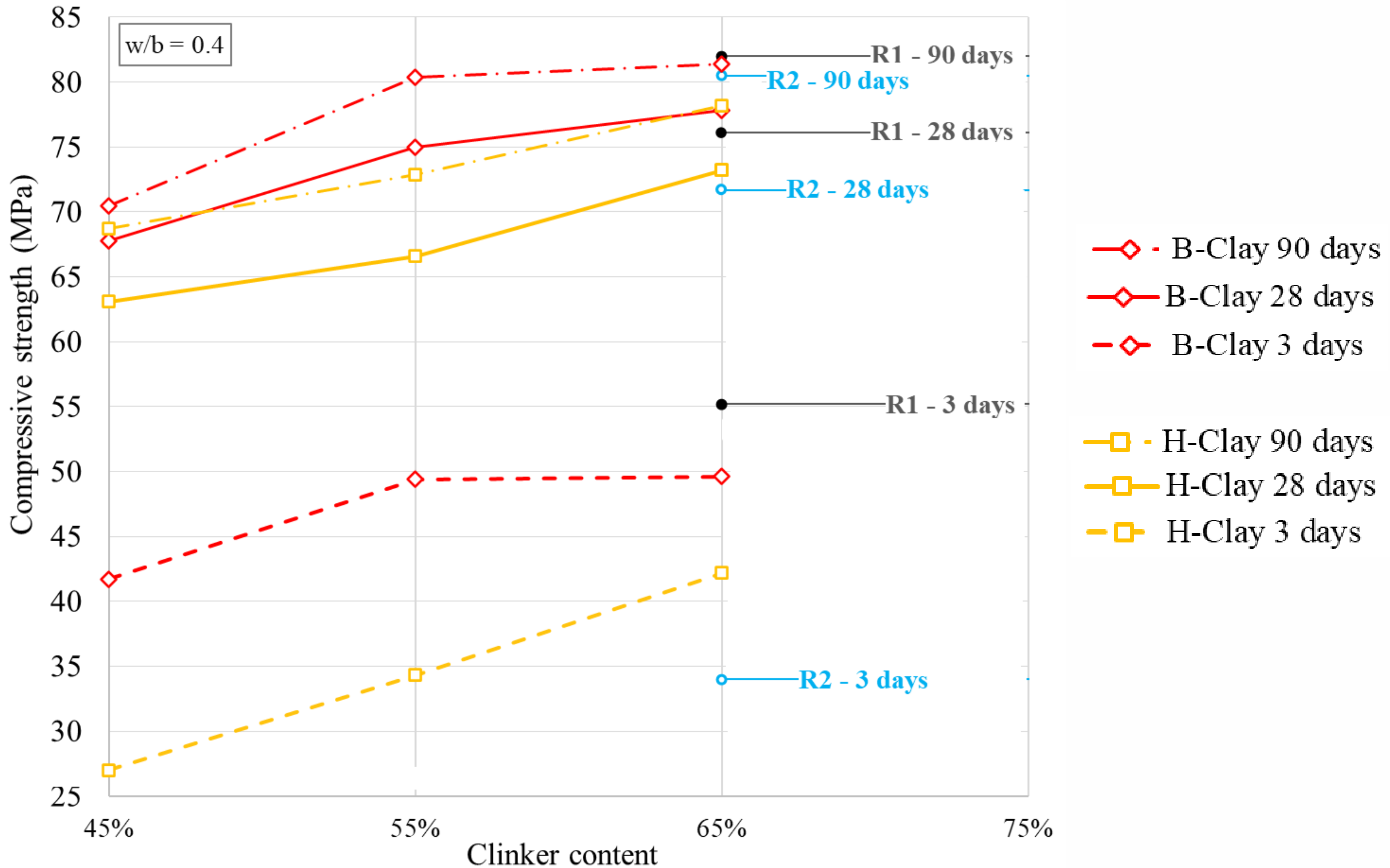
Concrete – strengths up to 90 days (w/b = 0.4)



Concrete – strengths up to 90 days (w/b = 0.55)



Concrete – Compressive strengths vs clinker factor



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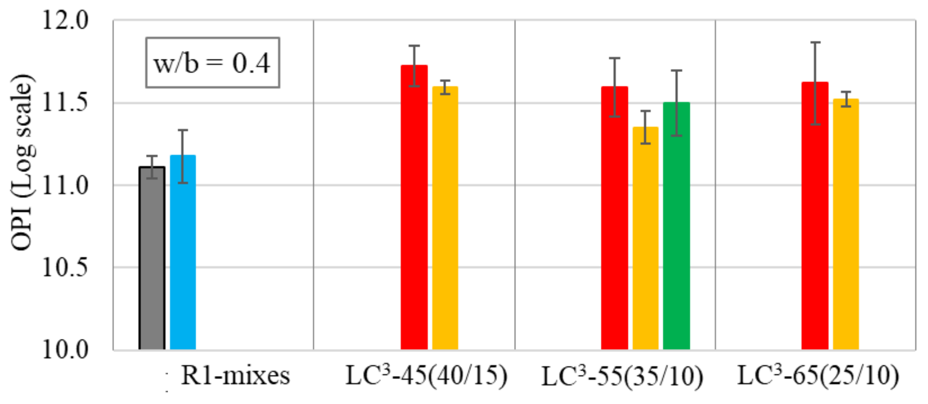
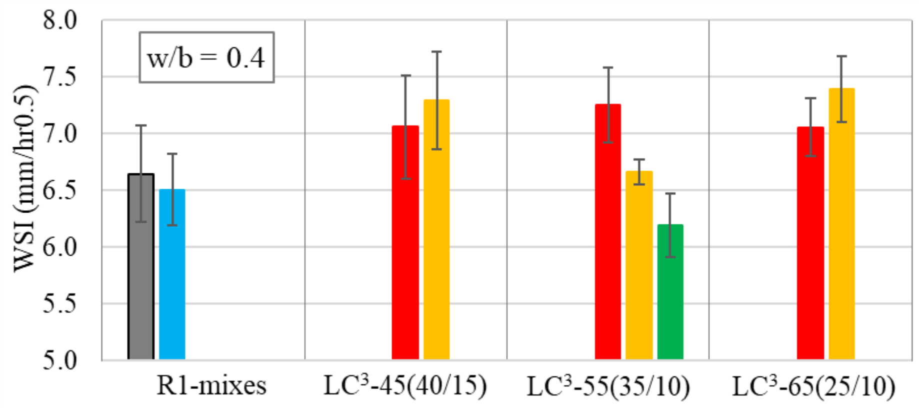
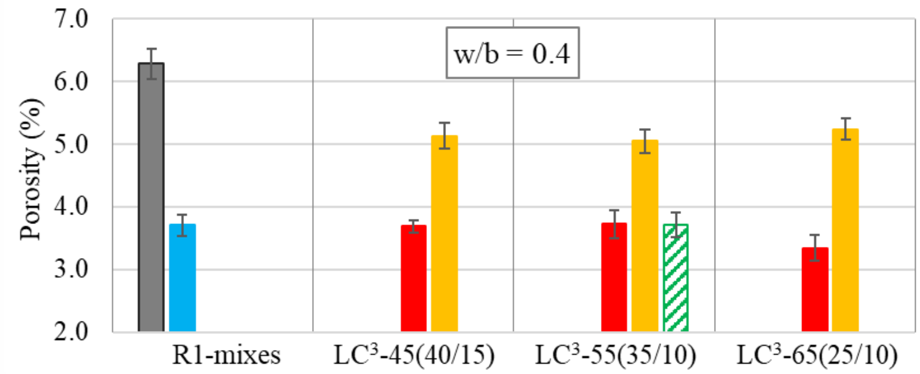
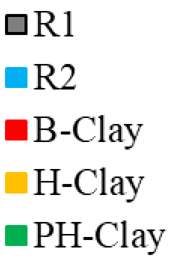
OPI, WSI and Porosity results : w/b = 0.4

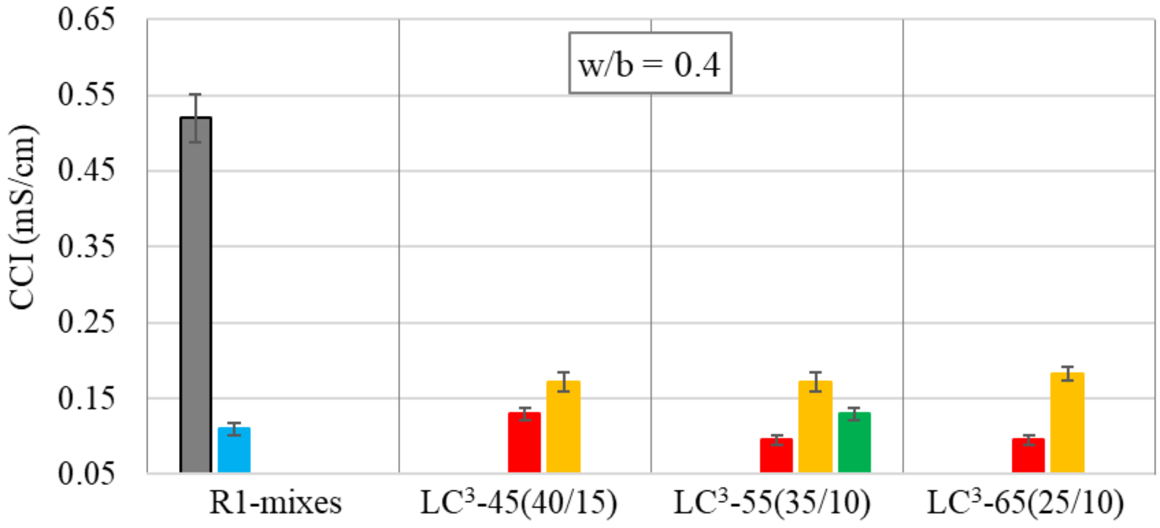


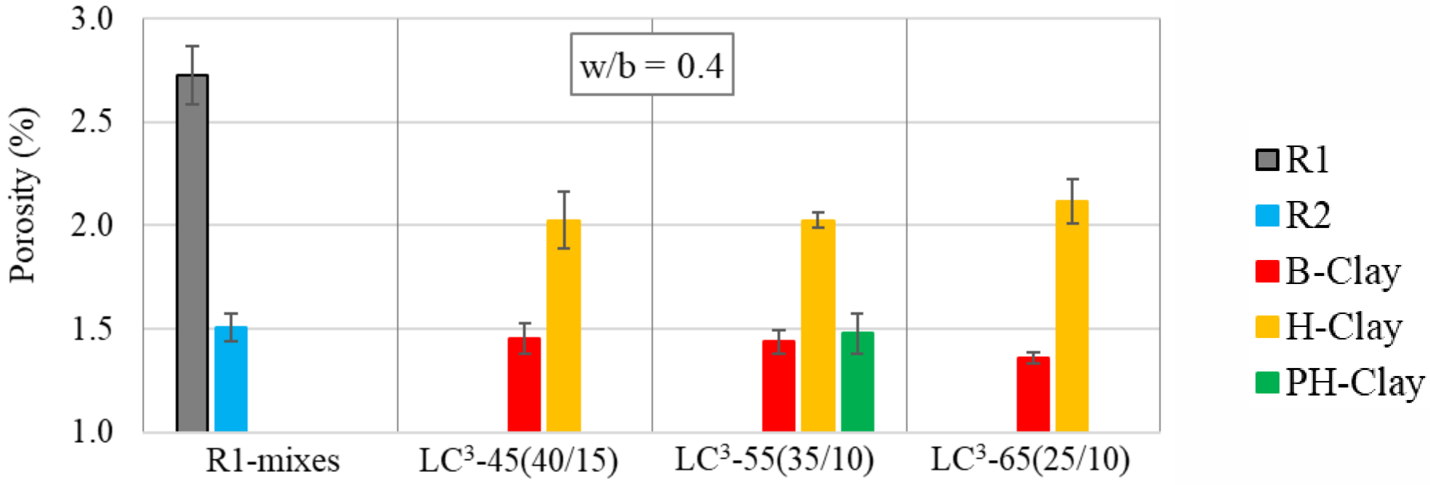




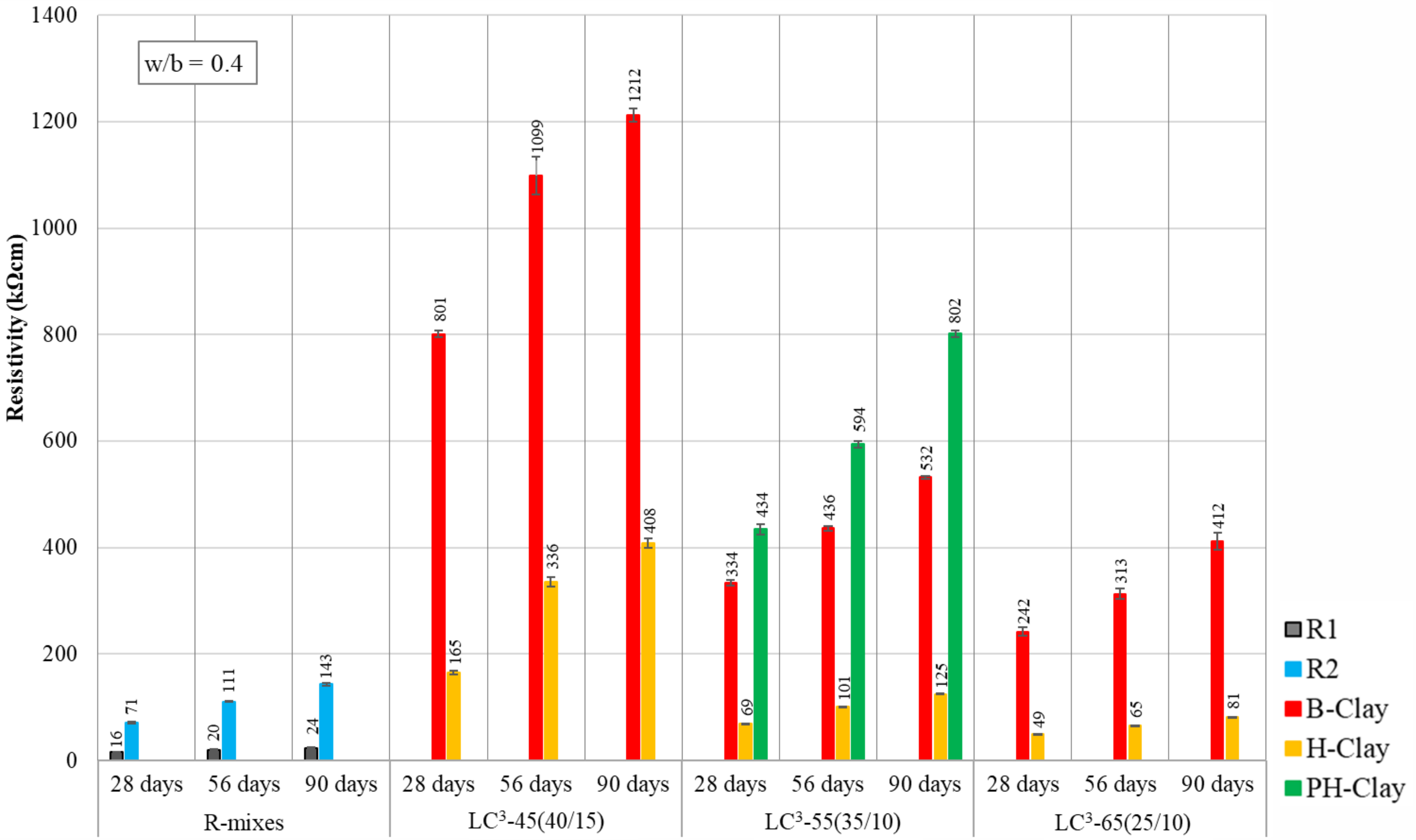


CCI results : w/b = 0.4

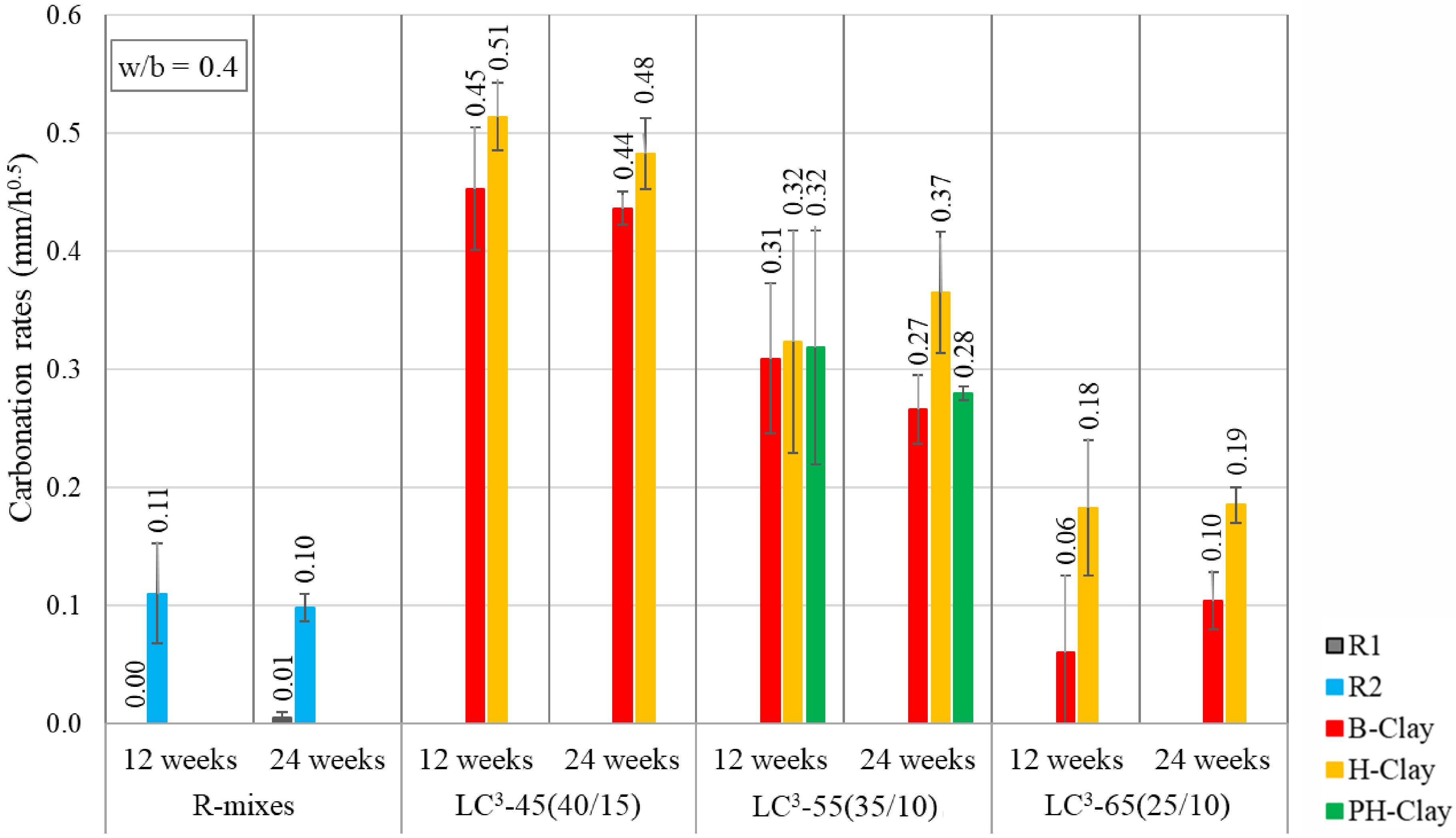




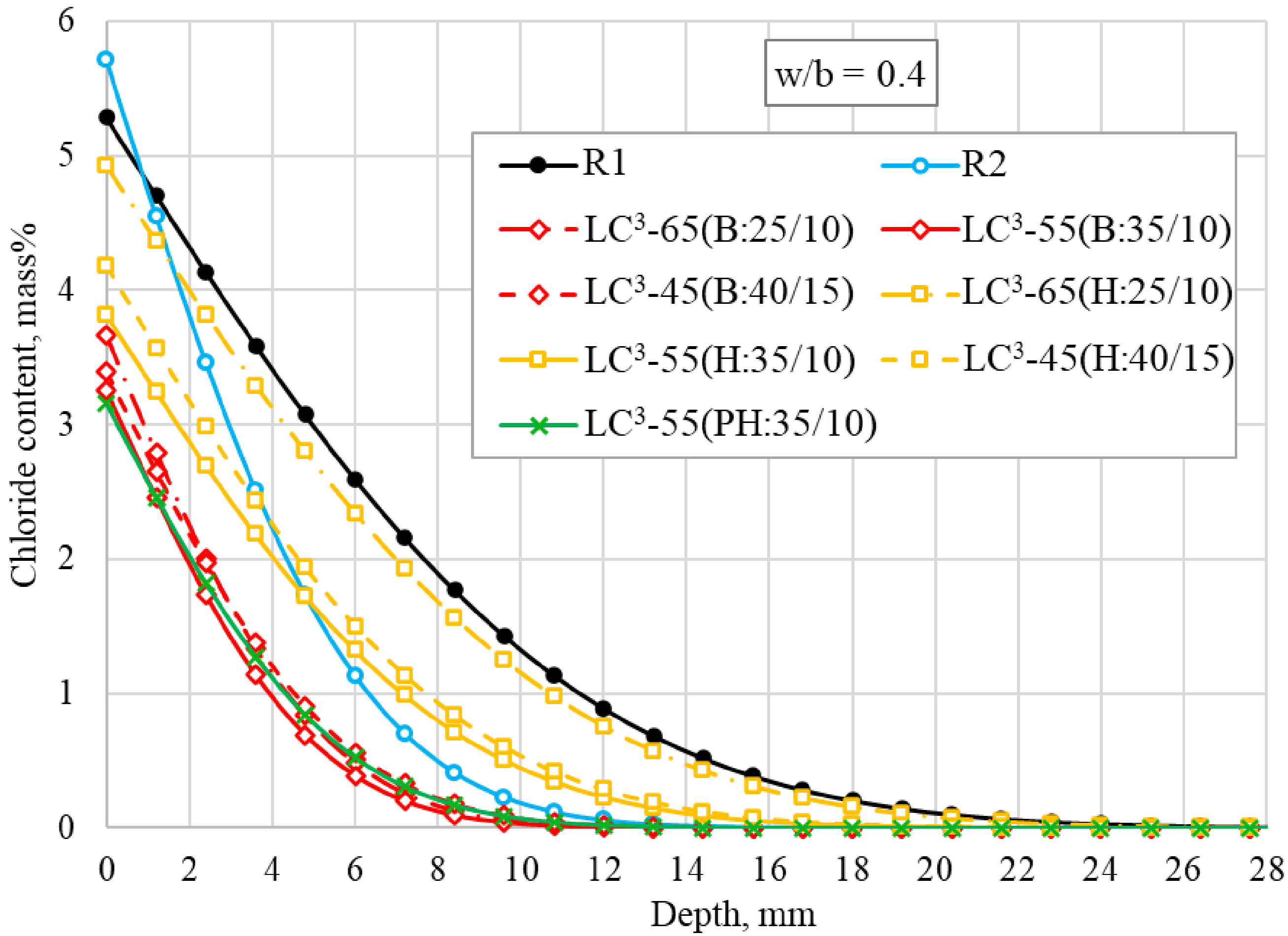
Resistivity: w/b = 0.4



Carbonation: w/b = 0.4



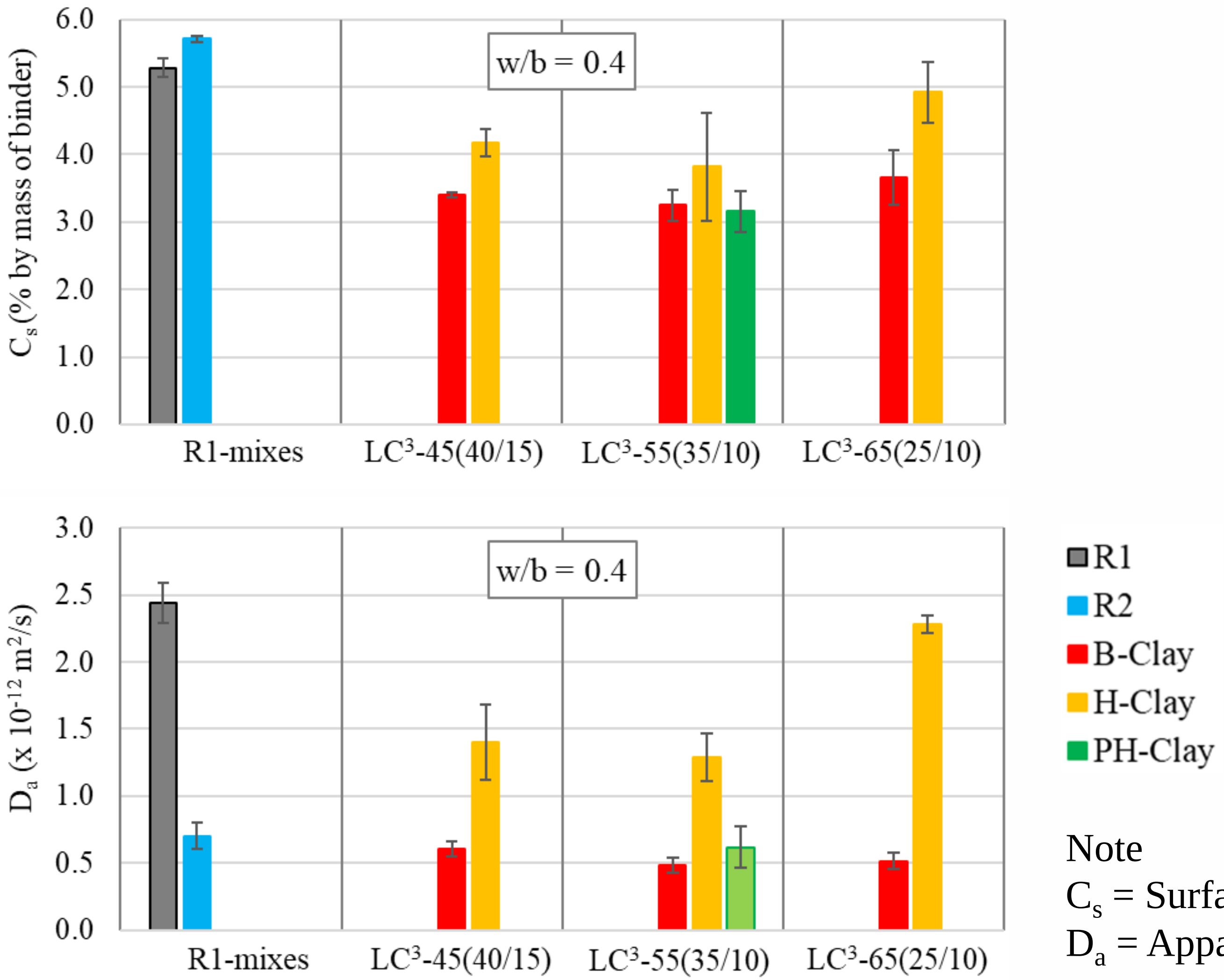
Bulk diffusion test results (ASTM C 1556)



Chloride profiles

(6 Months exposure)

Bulk diffusion test results (ASTM C 1556)



Note
C_s = Surface chloride concentration
D_a = Apparent chloride diffusion coefficien

Conclusion

- LC^3 system – Low-Cost and Low-CO_2 system
- All selected clays composed mainly of quartz, illite and kaolinite
- Optimum proportion 55% Clinker, 35% Calcined clay, 10% LS
- LC^3 mixes perform similar to, or better than the reference mixes
- Kaolinite clays are not the same – each source must be examined

Thank You

Dankie