LC^3 / LC^2 opportunities for fast and large scale decarbonisation and cost reduction of cement and concrete

Professor Karen Scrivener,
Fellow of the Royal Academy of Engineering, UK

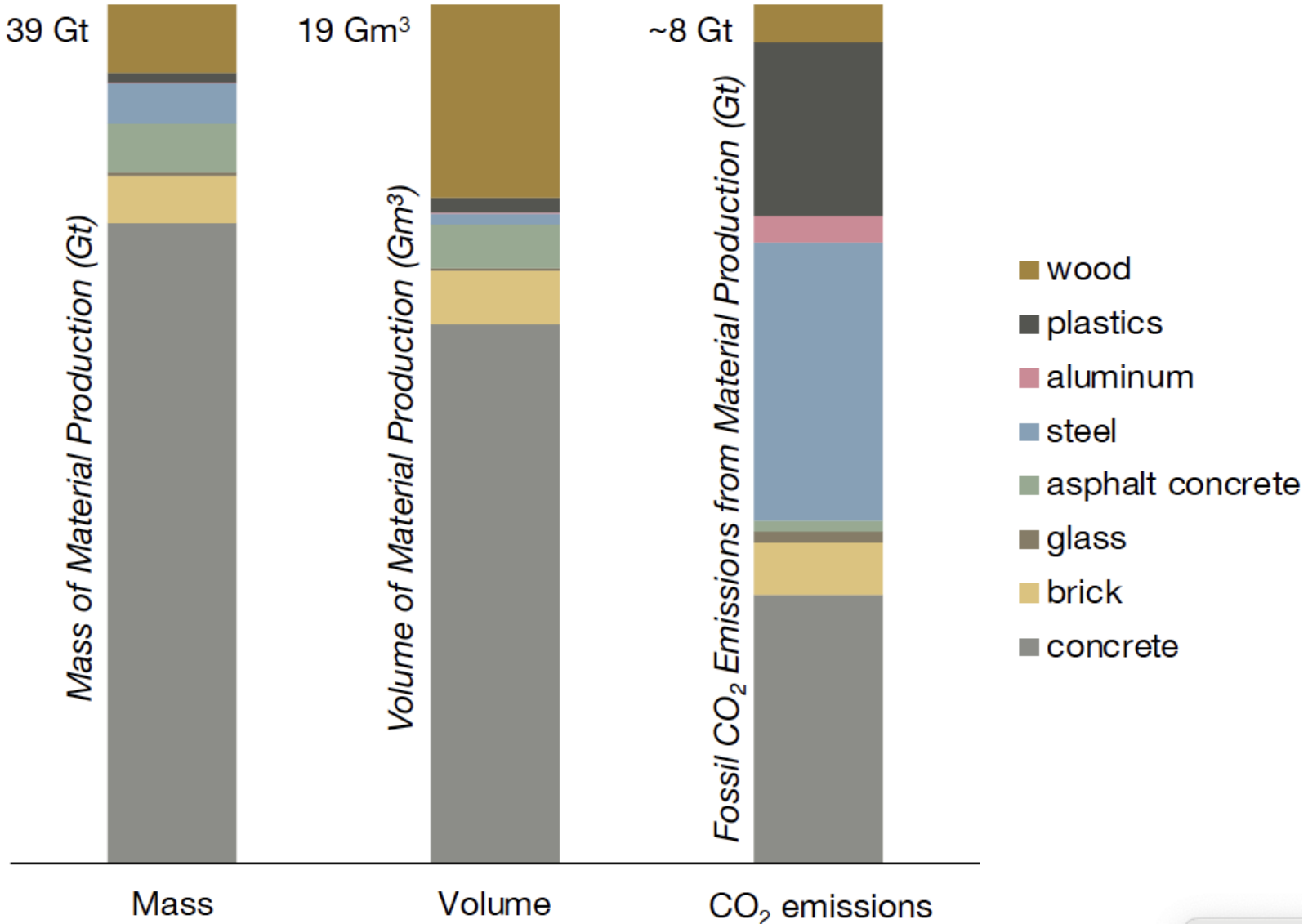
Large potential for LC3 :

- Blended cement with similar final composition existing products
  - Confidence in long term performance
- Already covered by existing standards (to some extent)
- High reactivity of calcined clays allows high levels of substitution
- Excellent resistance to chloride penetration and alkali silica reaction
- Suitable clays widely available

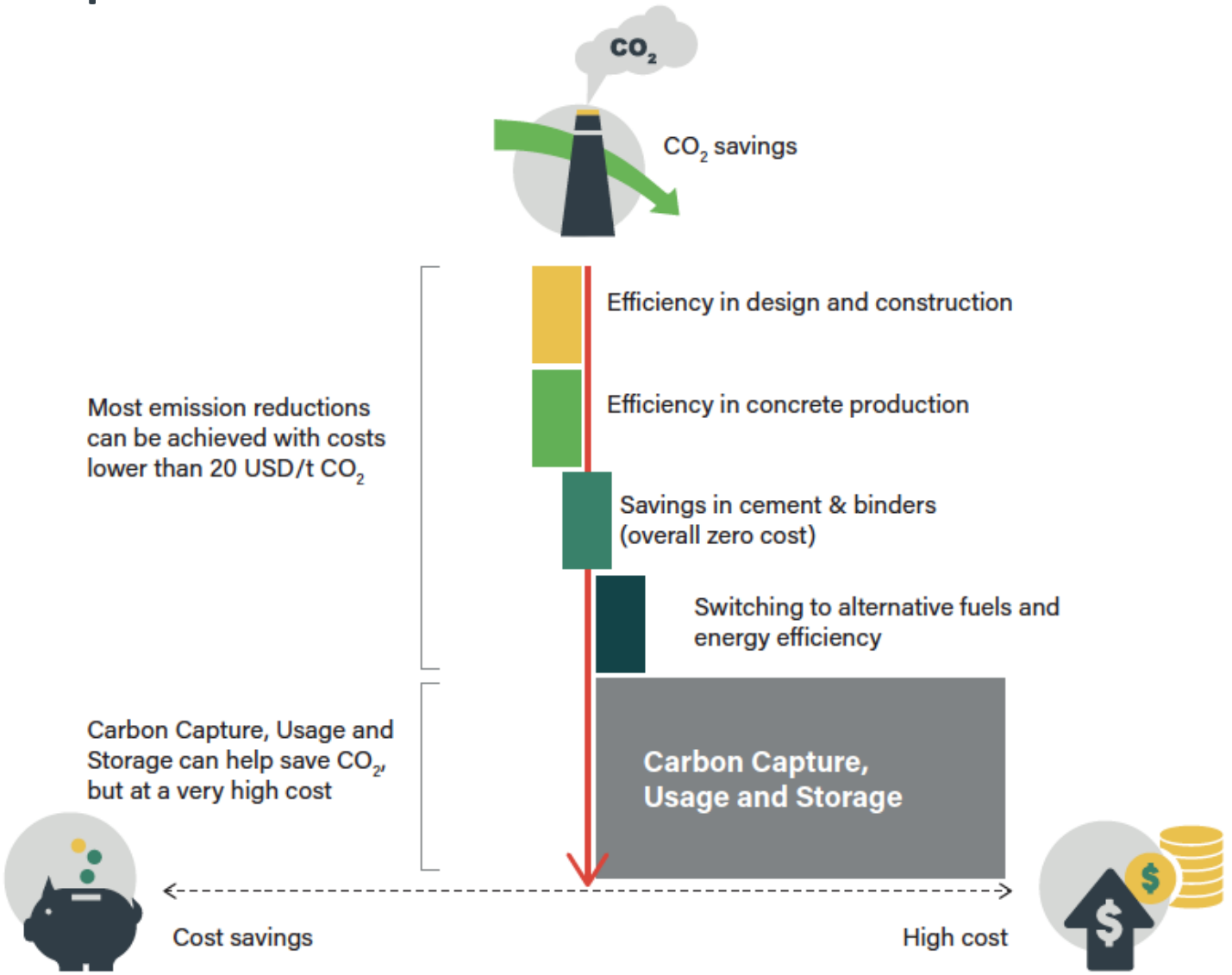
Issues

- Clays need to be identified
- Needs calcination process
- Different workability

ALL Materials



Much of the path to net zero is low cost



“Portland” cement
is an inevitable consequence of
the chemistry and geology of the earth

No alternative can be produced in quantities needed:

Limestone Calcined Clay Cement LC3 www.LC3.ch

Most promising approach – reducing the clinker factor

LOW CARBON LOW COST LOW CAPITAL HIGH PERFORMANCE

↓ CO_2

Process optimisation

↓ clinker factor

Clinker + Gypsum → Cement

\+ SCMs – Supplementary Cementitious Materials

Limestone

Fly ash

Slag

Calcined clays

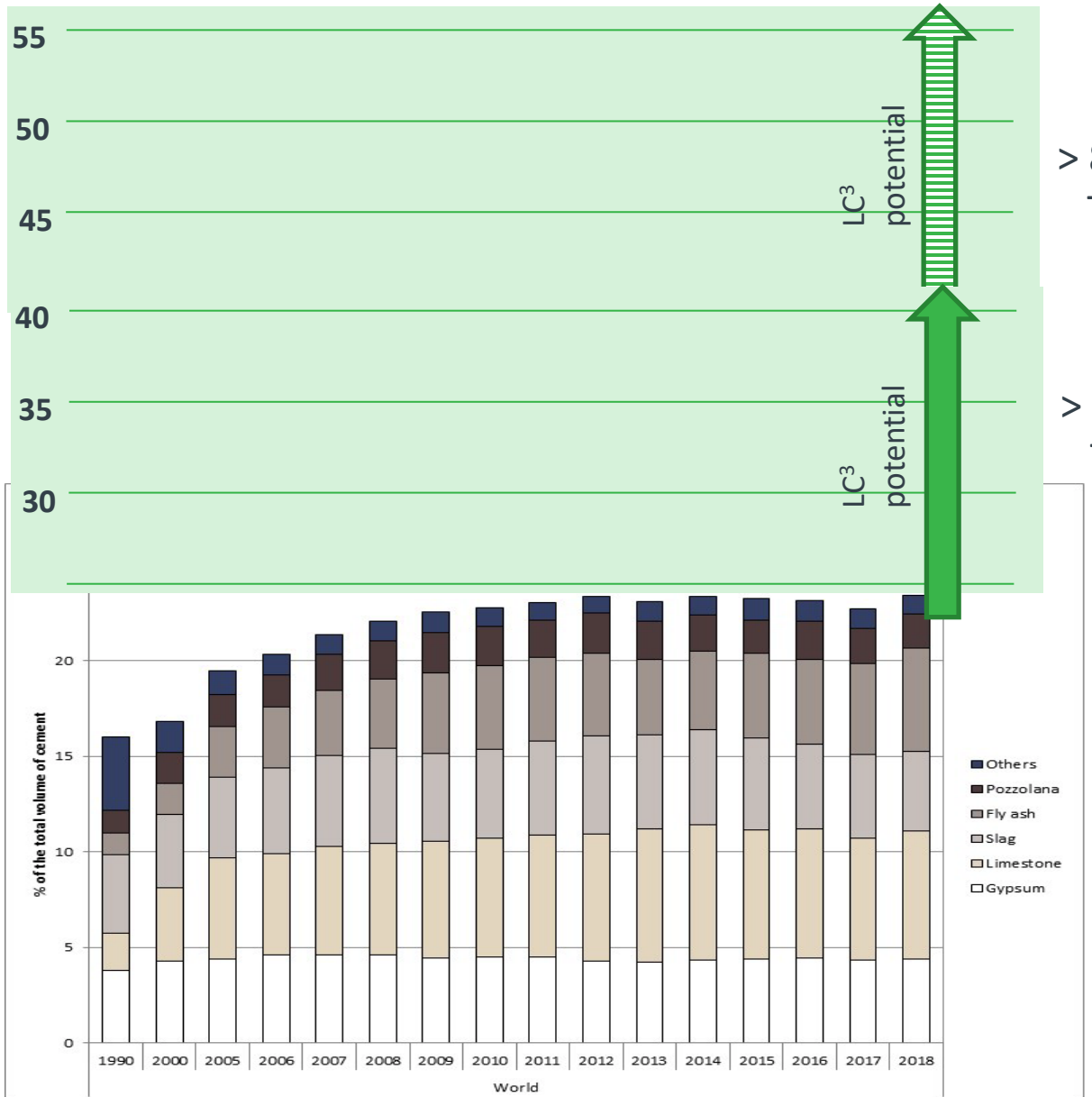
Often by-products or wastes from other industries

Availability of SCMs

Limestone Calcined Clay Cement
LC3
www.LC3.ch

LOW CARBON LOW COST LOW CAPITAL HIGH PERFORMANCE

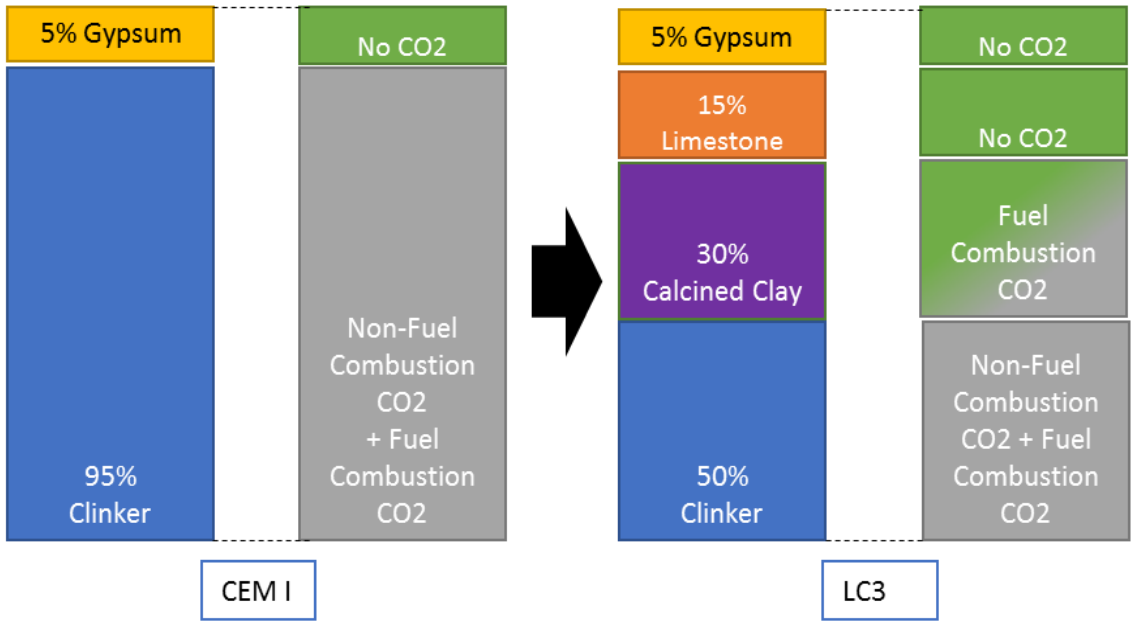
Calcined Clay only Supplementary Cementitious Materials which can expand substitution

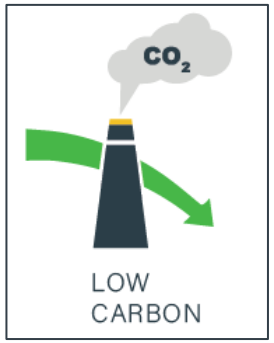


> 800 million Tonnes CO_2/yr

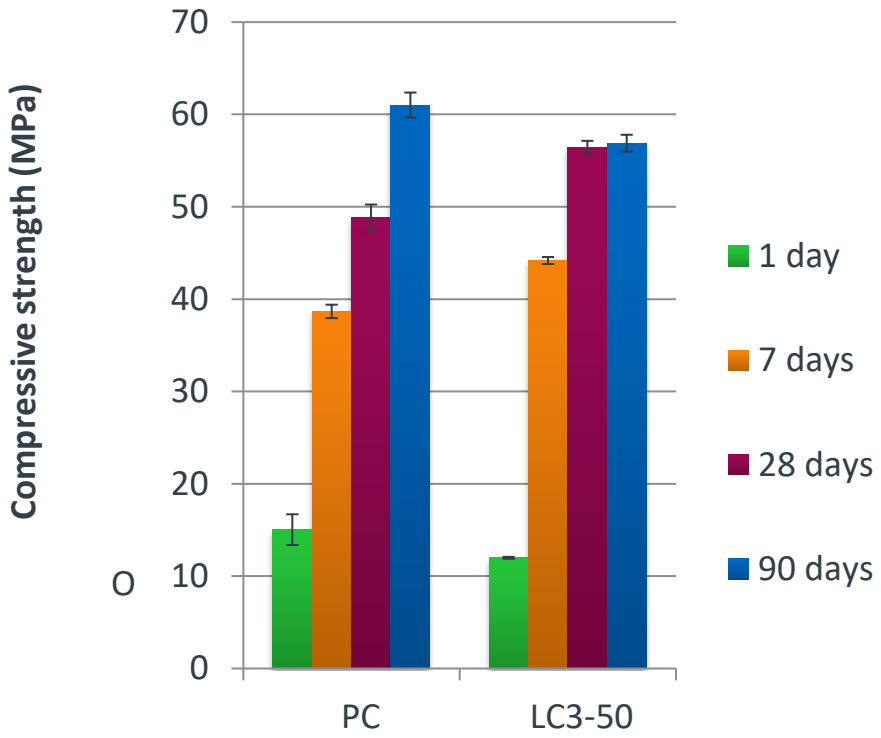
> 400 million Tonnes CO_2/yr

How does LC^3 reduce emissions?





LC^3 has comparable strength to OPC

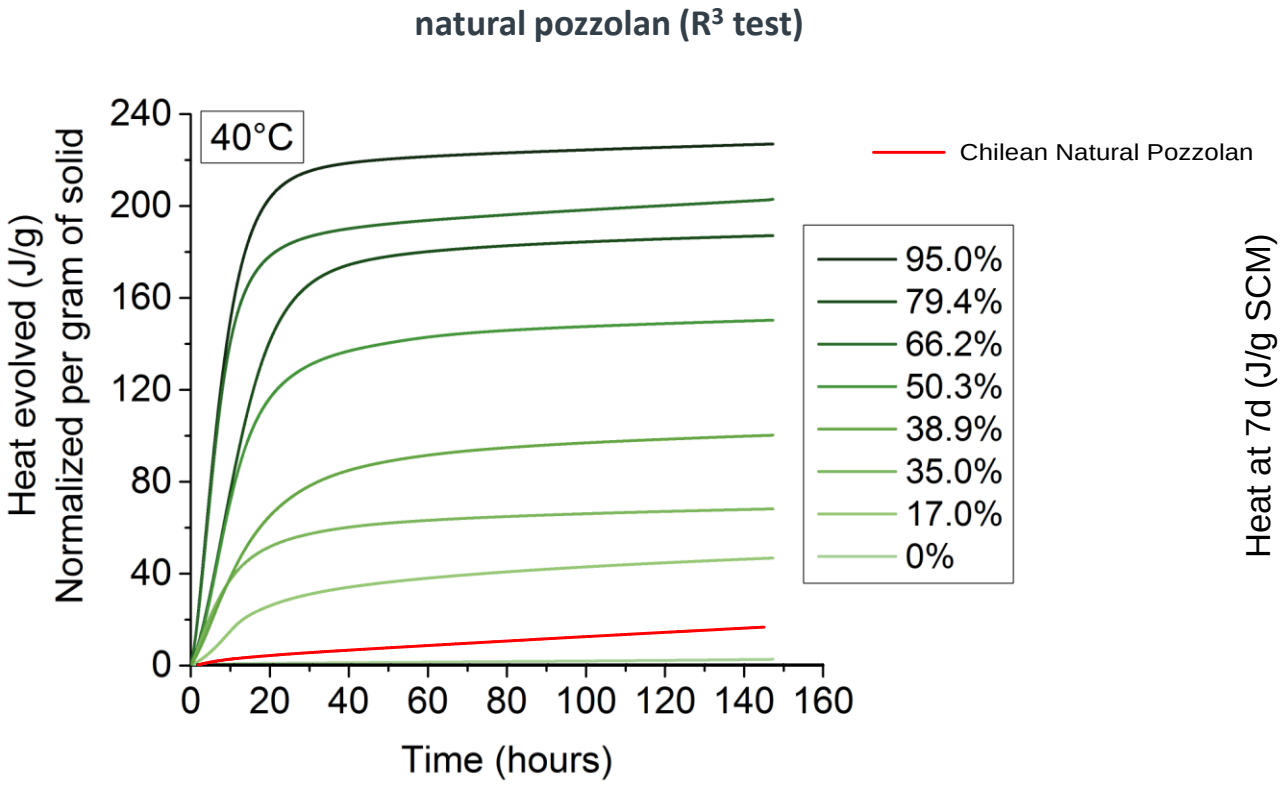


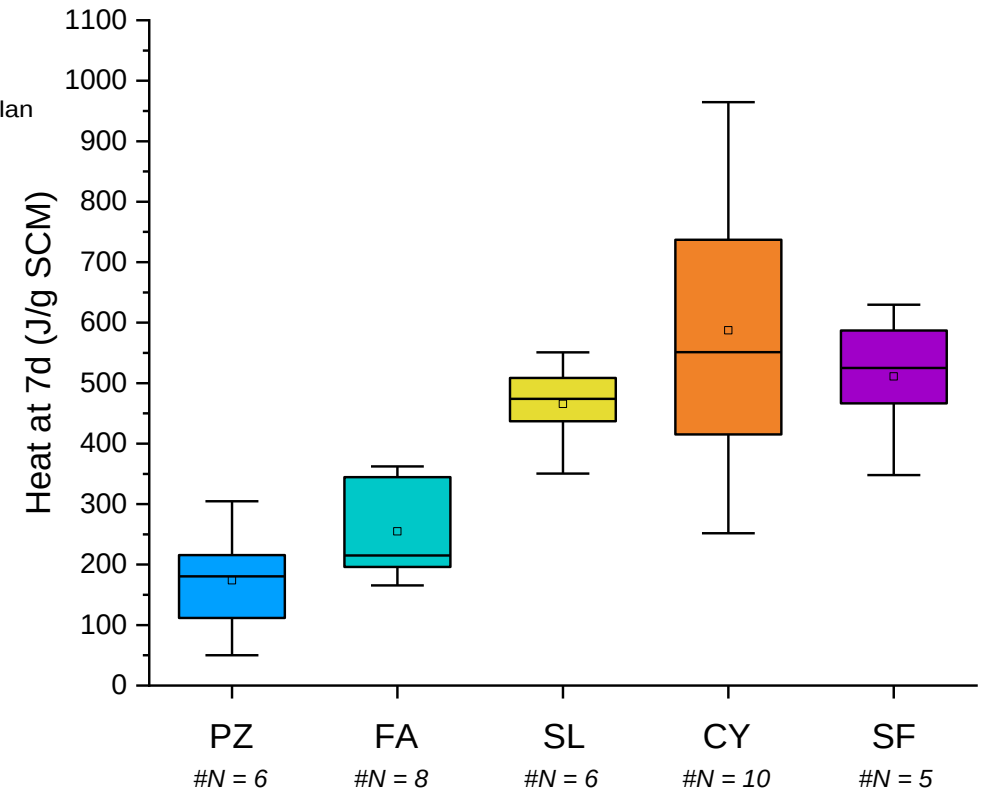
LC3-50 = 50% clinker.

- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

HIGH PERFORMANCE

Calcined clay vs. other pozzolans





Kaolinitic clay with the lowest kaolinite content is more reactive than most pozzolans commonly used in the industry!!

Comparison with natural pozzolans, example Chile

Roadmap ICH/FICEM 2019

- Pozzolanic cements have been in widespread use since the 1960s
- Standardization built around the cements available in the local market

High strength (80% CK)

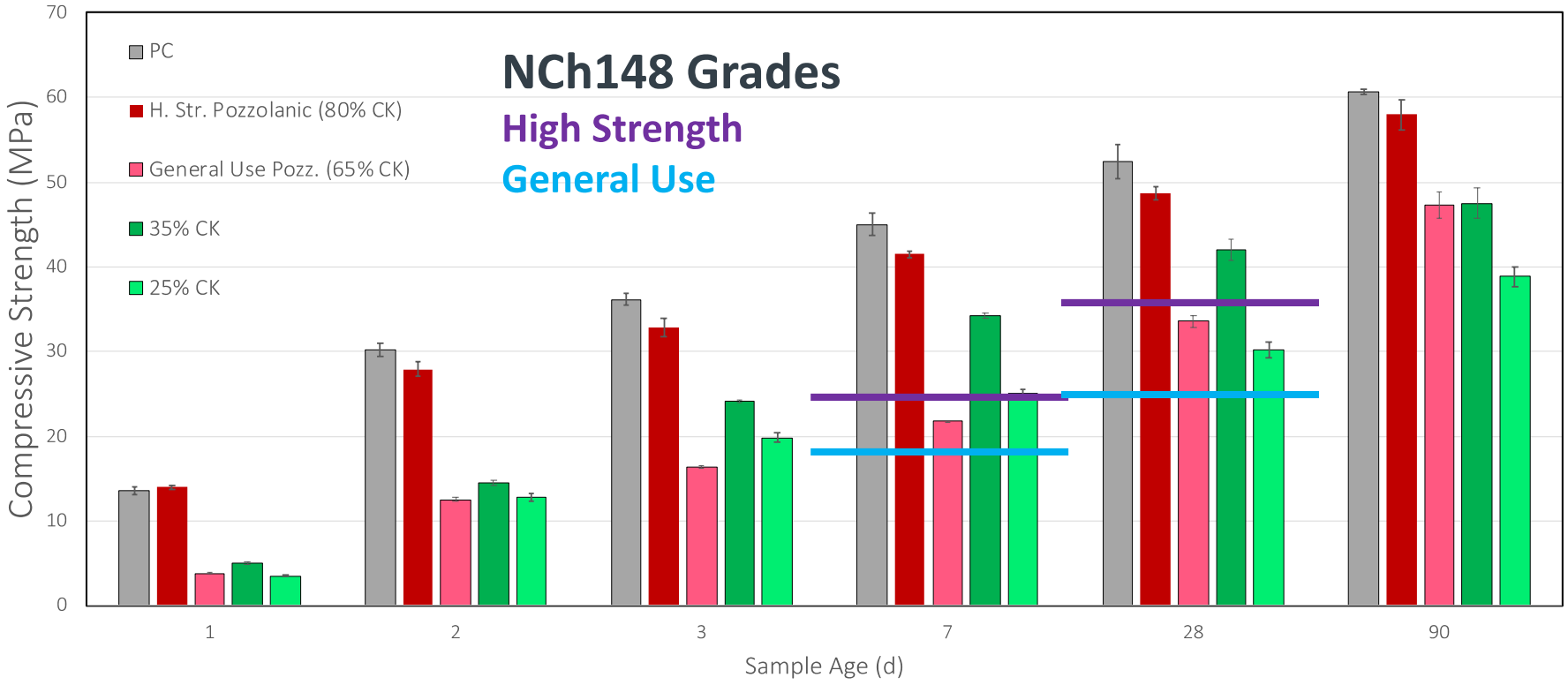
General use (65% CK)

LC³-35 (35% CK)

LC³-25 (25% CK)

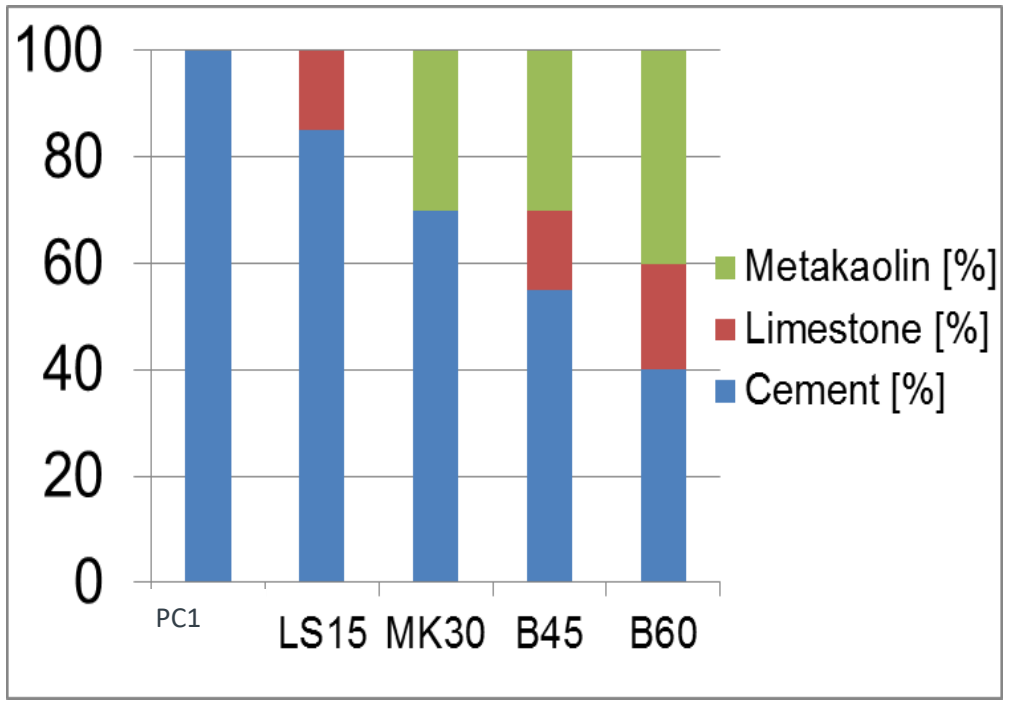
Clinker savings

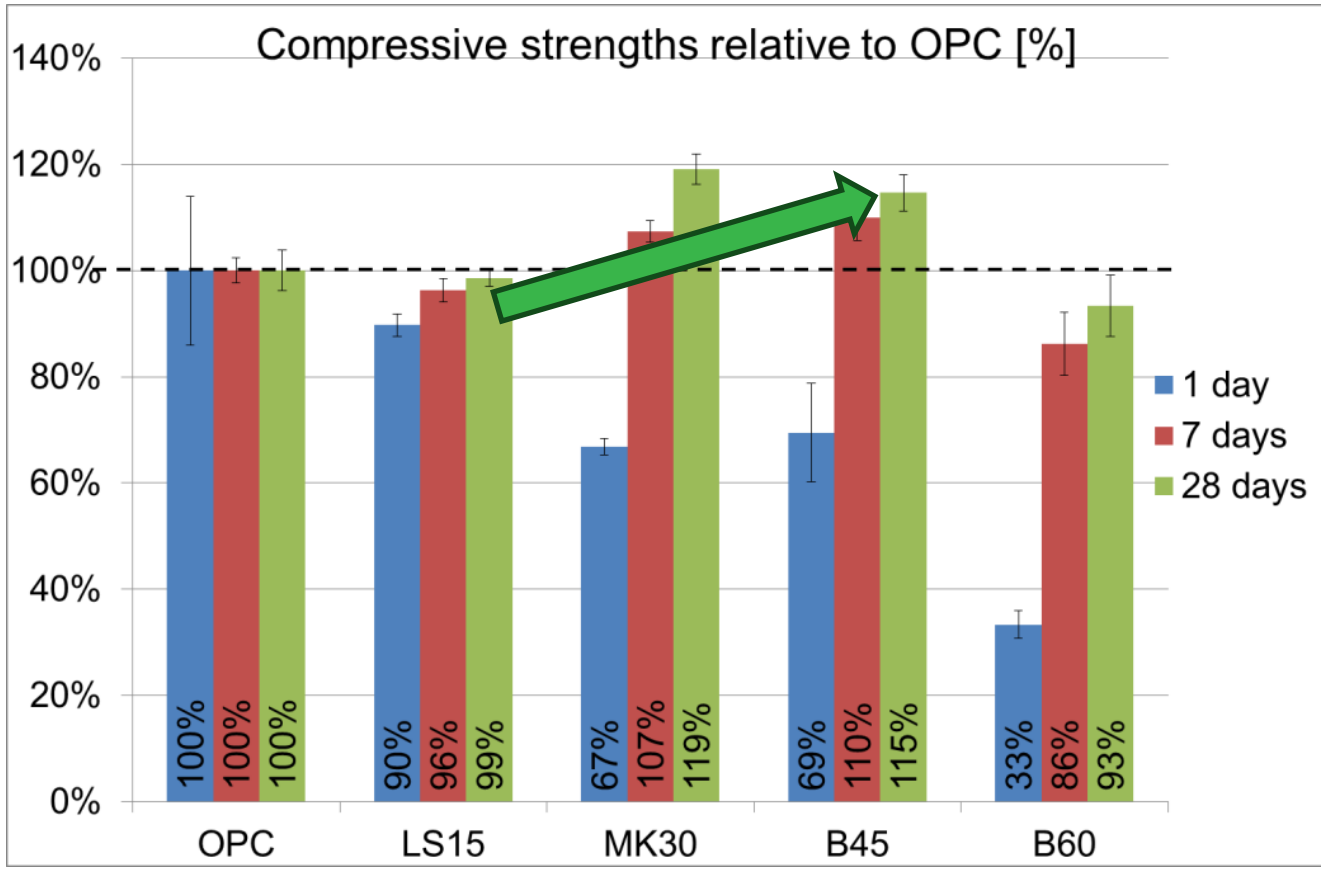
40-45%



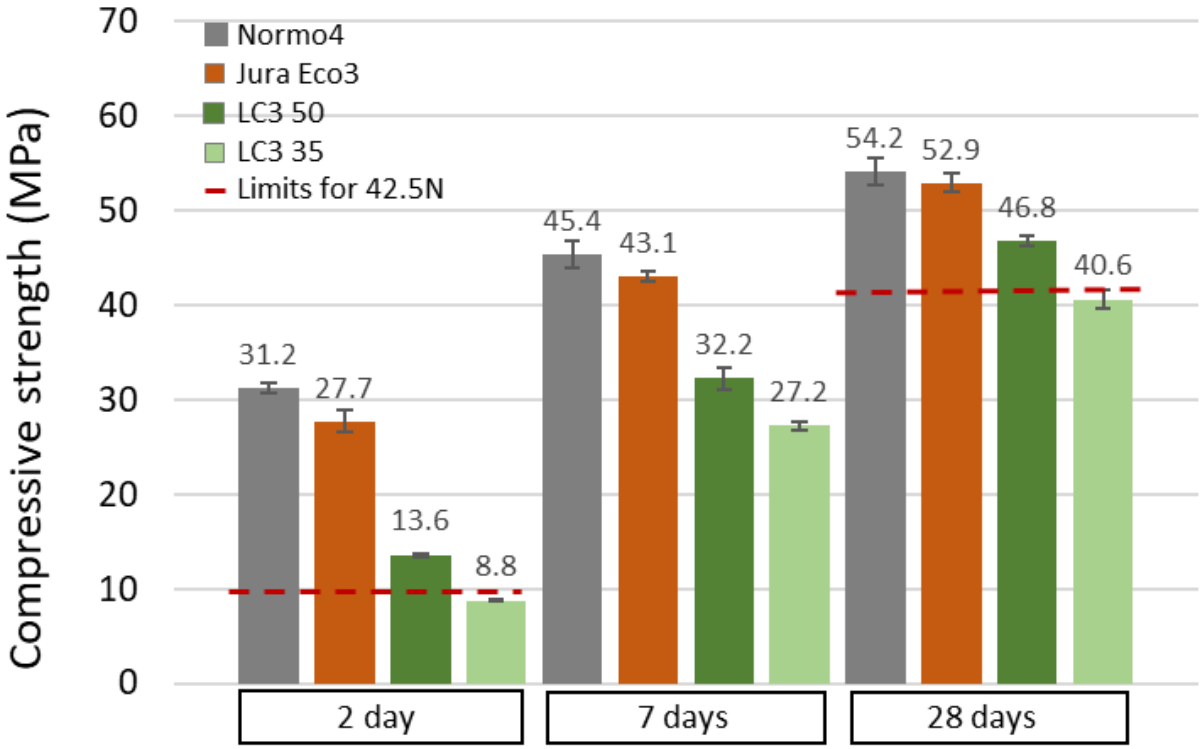
The reactivity of SCMs matters!

Addition of calcined clay to limestone blends: strength higher than OPC reference at 28 days

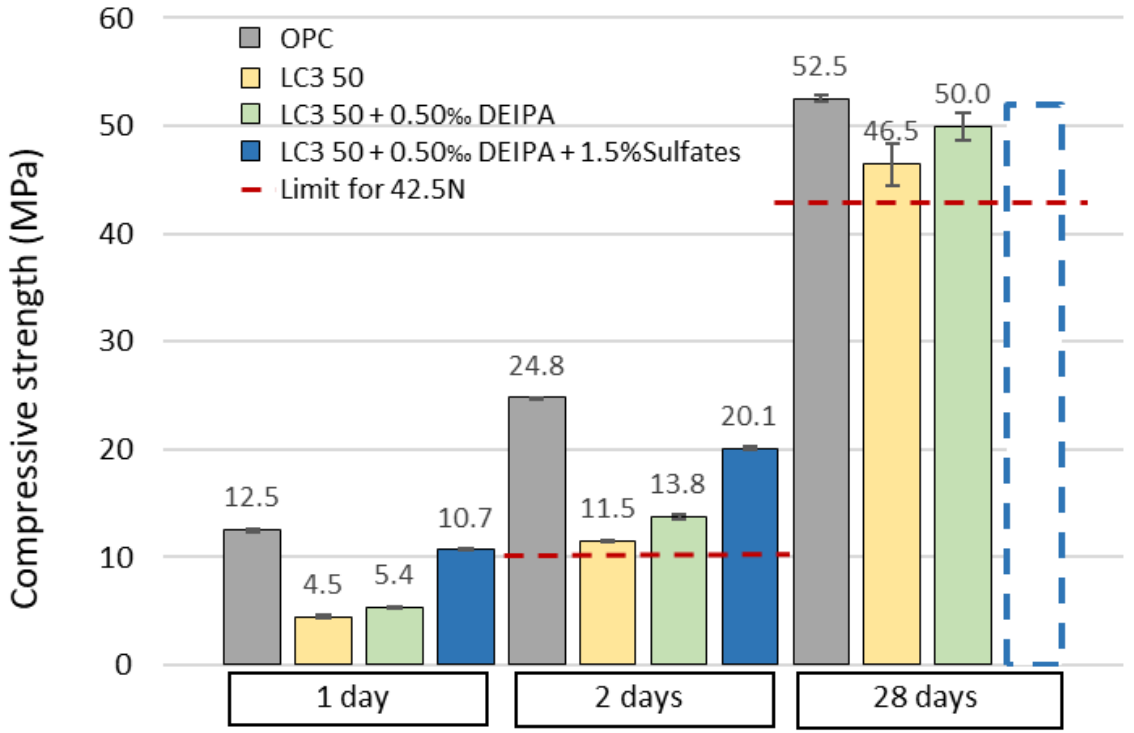




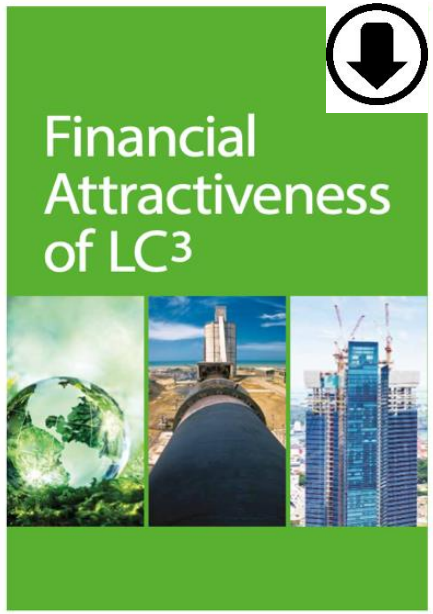
Juracim Coraux Switzeland: much better results than in the lab



CEM II/C M(Q-LL)



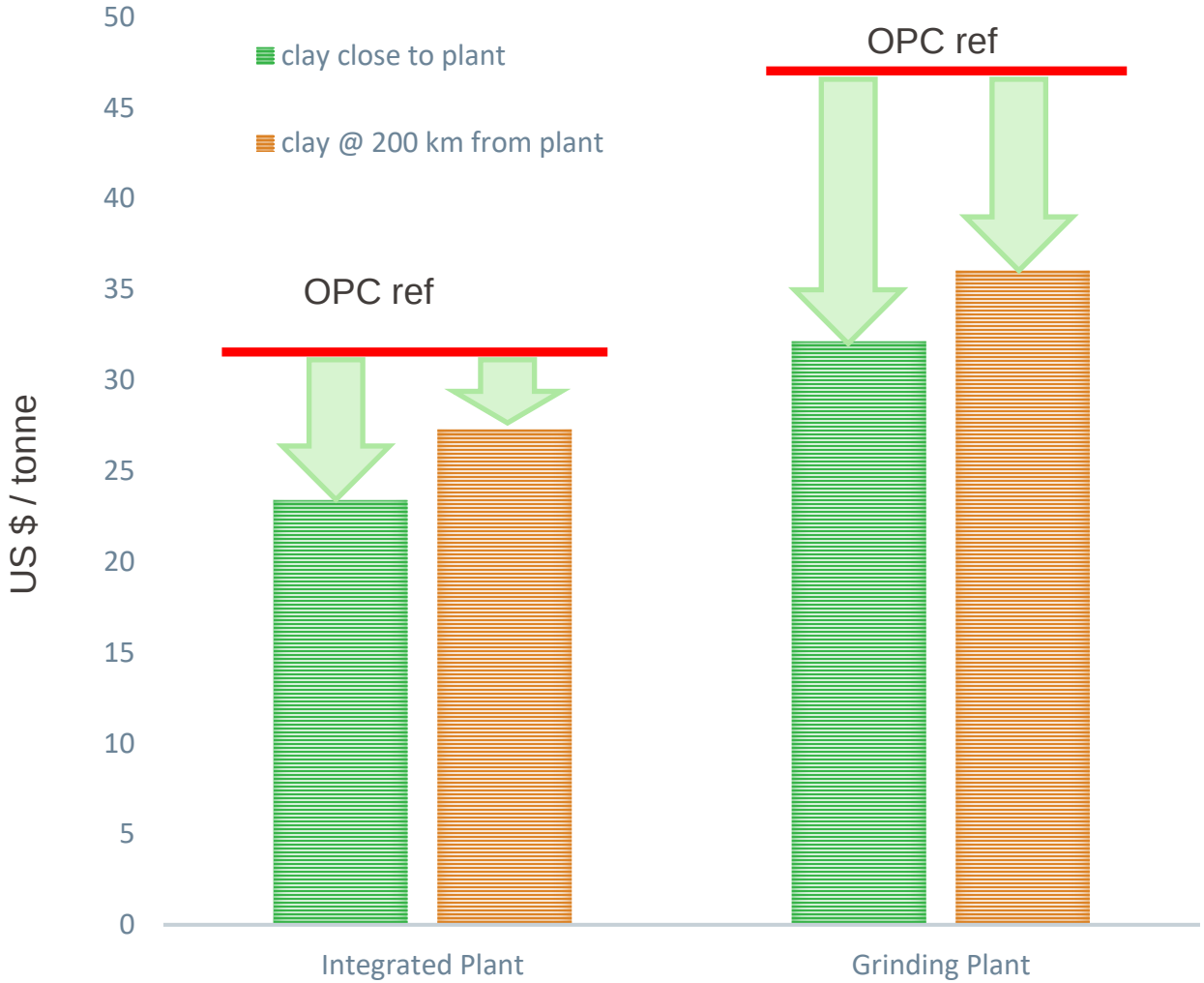
Financial Feasibility



Report available to download:
www.lc3.ch

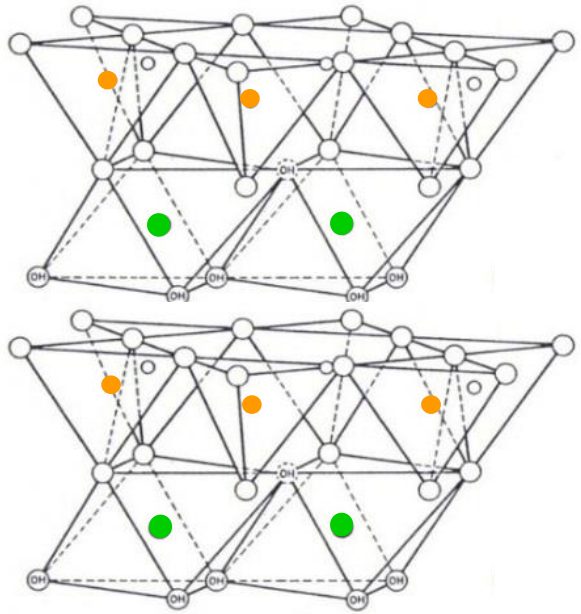
Study by LC3 Project partner CEMENTIS

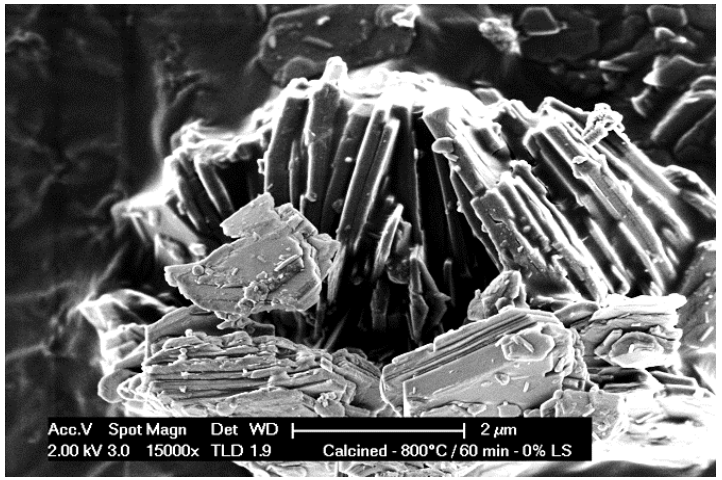
LOW CAPITAL



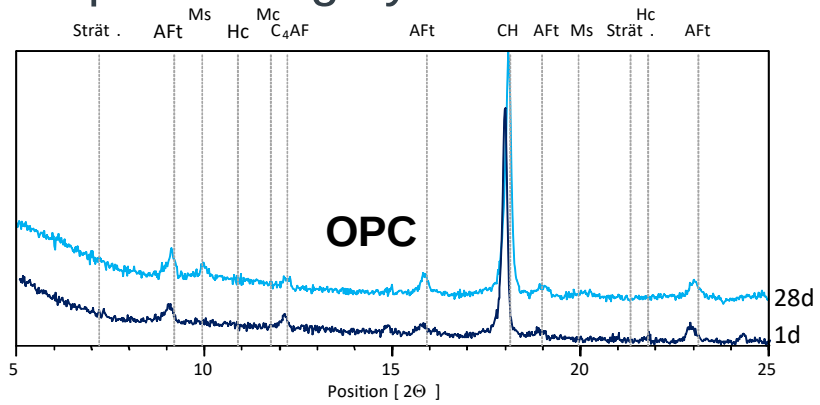
Why can we get such high replacement levels?

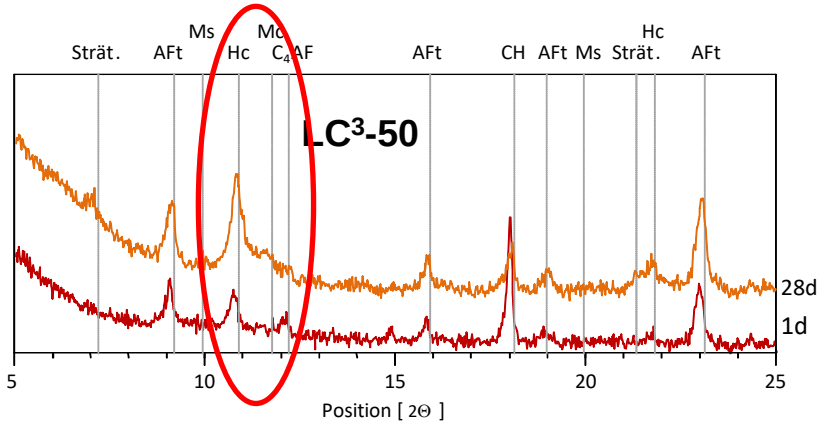
- Calcination of kaolinite at **700-850°C** gives metakaolin: much more reactive than glassy SCMs





- **Synergetic reaction** of Alumina in metakaolin with limestone to give space filling hydrates

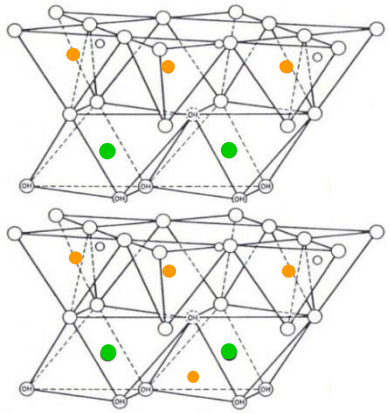




What kinds of clay are suitable?

Three basic clay structures

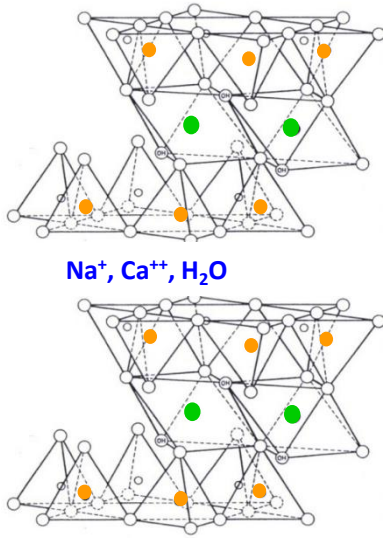
Kaolinite (1:1)



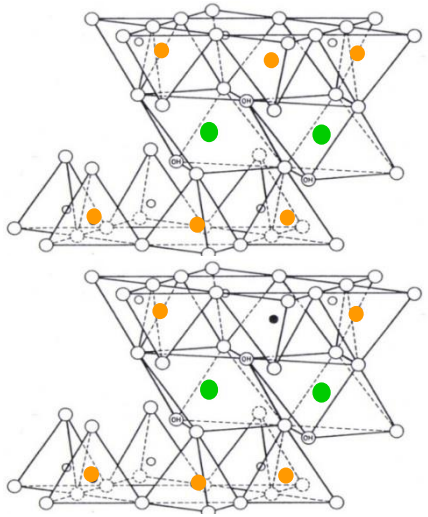
aluminium

silicon

Montmorillonite (2:1)
(Smectites)



Illite (Micas)
(2:1)

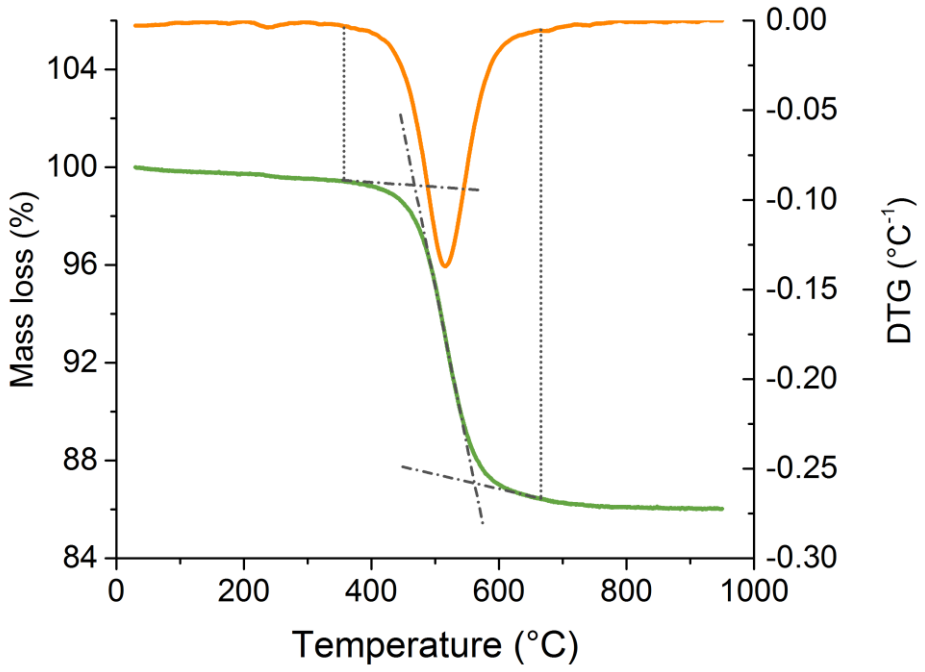


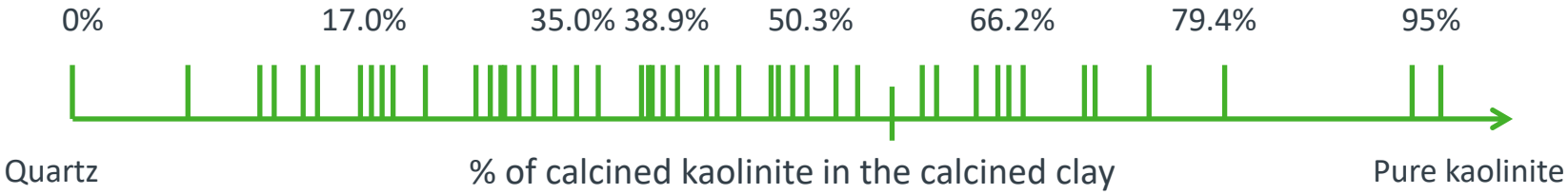
"Metakaolin", sold as high purity product for paper, ceramic, refractory industries
Requirements for purity, colour, etc, mean expensive 3-4x price cement

Clays containing metakaolin available as wastes
– over or under burden NOT agricultural soil
Much much less expensive often available close to cement plants

Over 70 clays studied from around the world

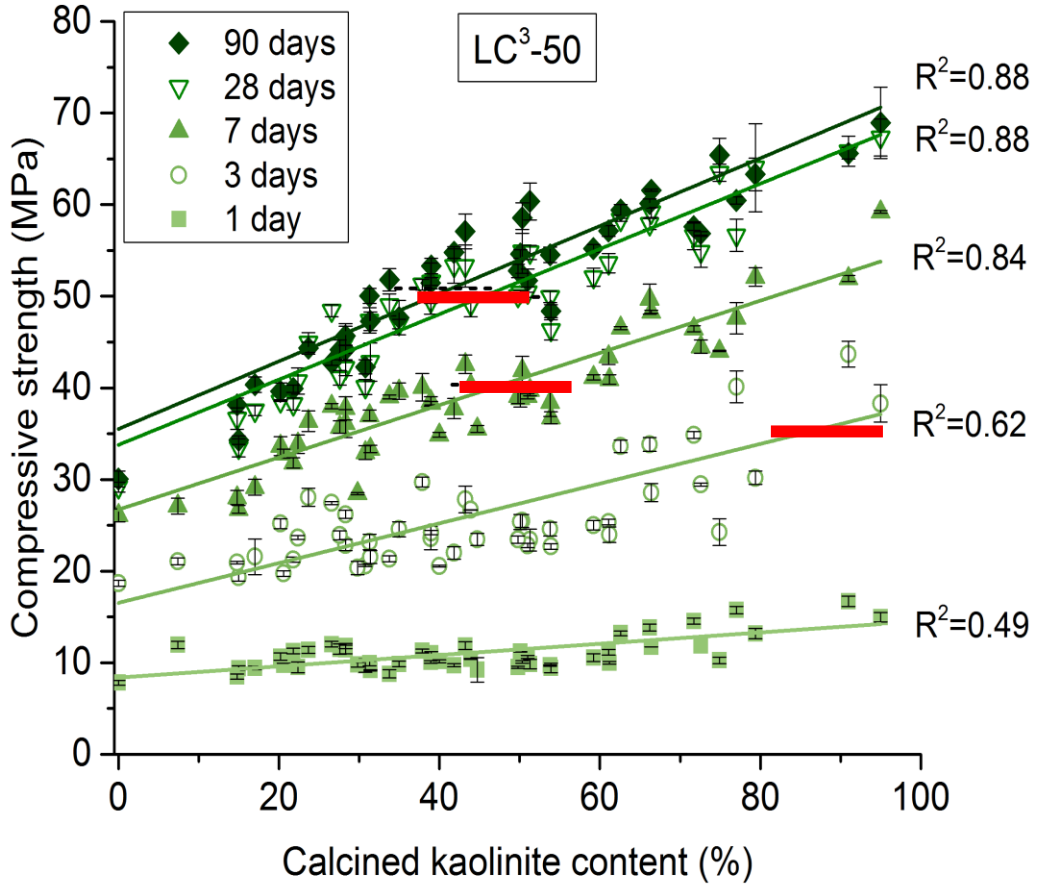
Different calcination conditions
Different compositions, impurities
Different physical properties





Benchmark test of clay strength

- Compressive strength EN 196-1 at 1, 3, 7, 28, 90 d
- Linear increase of strength with the MK content of calcined clays
- Similar strength to PC for blends containing 40% of calcined kaolinite from 7d onwards
- At 28 and 90 days, little additional benefit >60%
- Minor impacts of fineness, specific surface and secondary phases



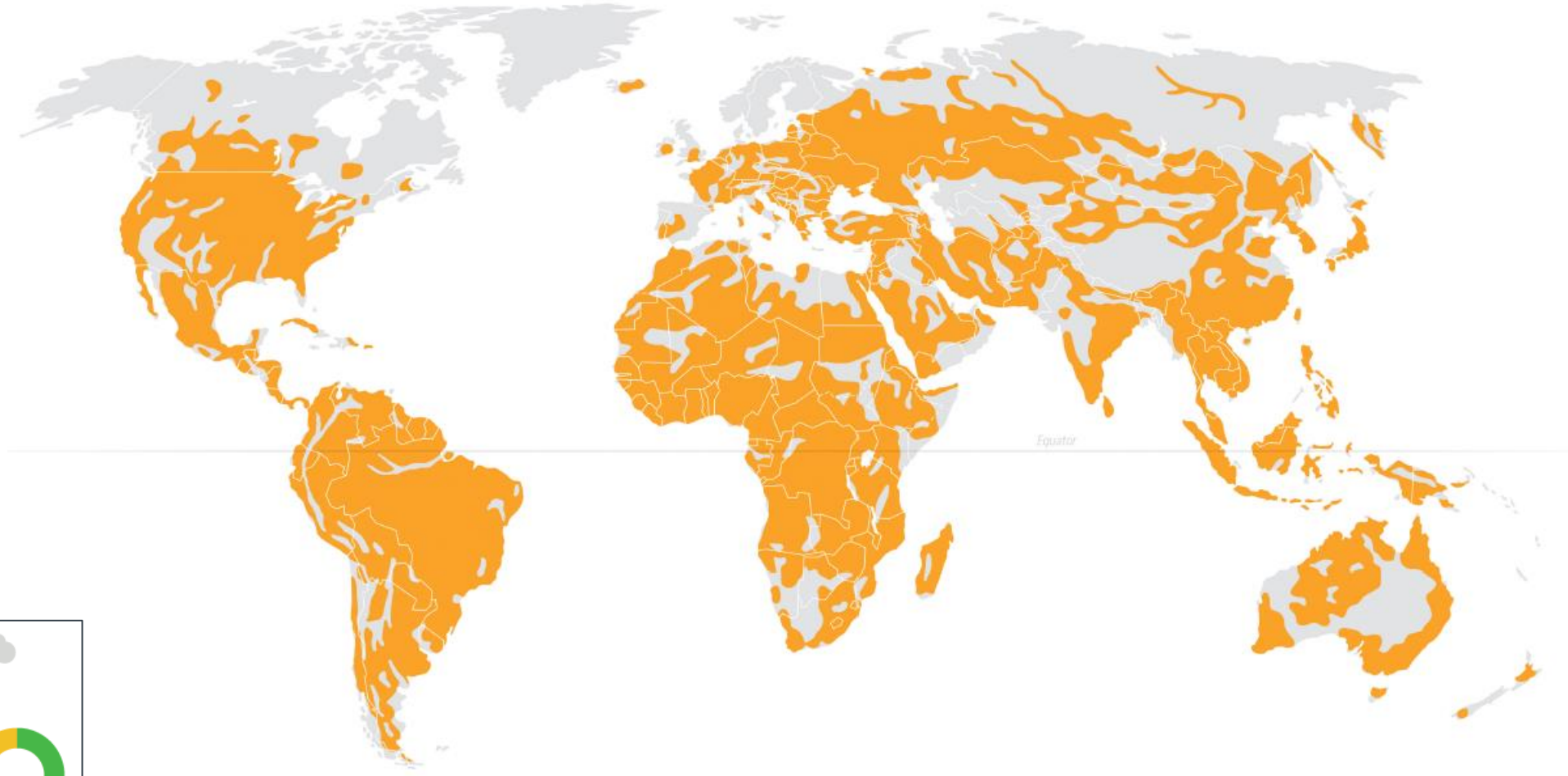
Calcined kaolinite content overwhelming parameter

Need any material with >30% kaolin

- Cement plant quarry silico-aluminate source – often part least suitable for clinker
- Aggregate washings
- Industrial Solid Wastes:
  - Mine Tailings
  - Over / underburden from ceramic grade quarries
  - etc

Suitable clays presently stockpiled as waste

World distribution of kaolinitic clays



SCALABLE

Source: Ito and Wagai, Scientific data 2017

In use qualities

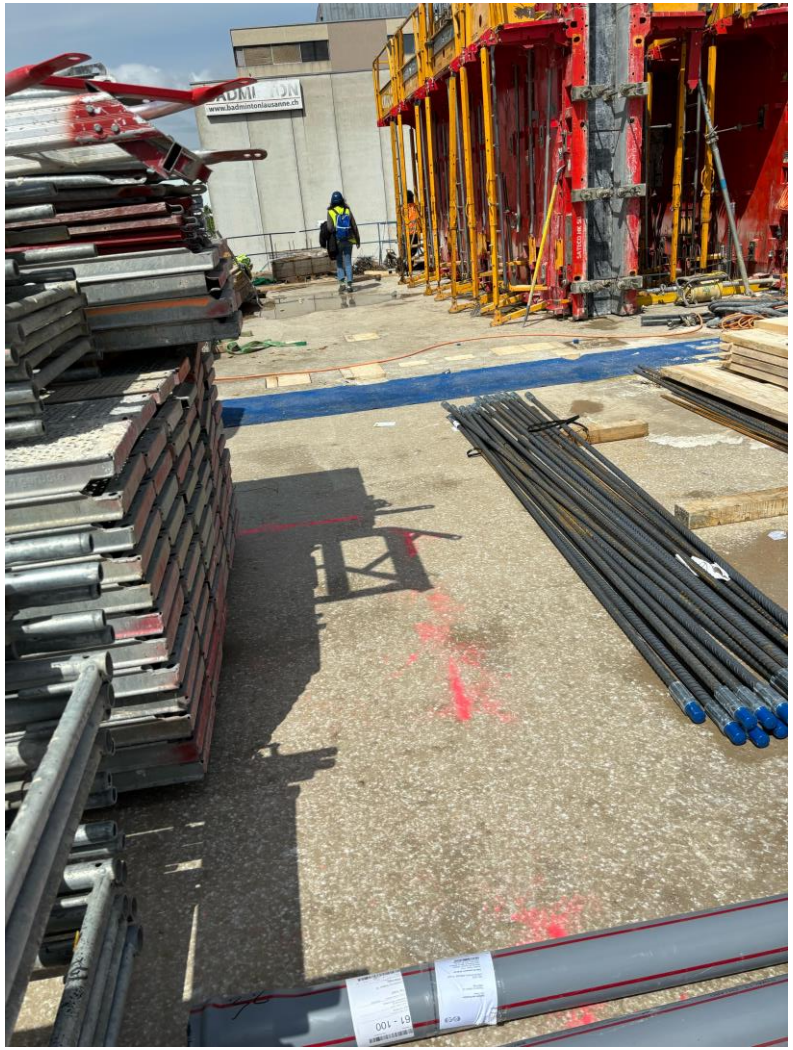
Self compacting concrete: cohesion

50% FA: 1.5% WRA

50% LC^2: 1.2% WRA

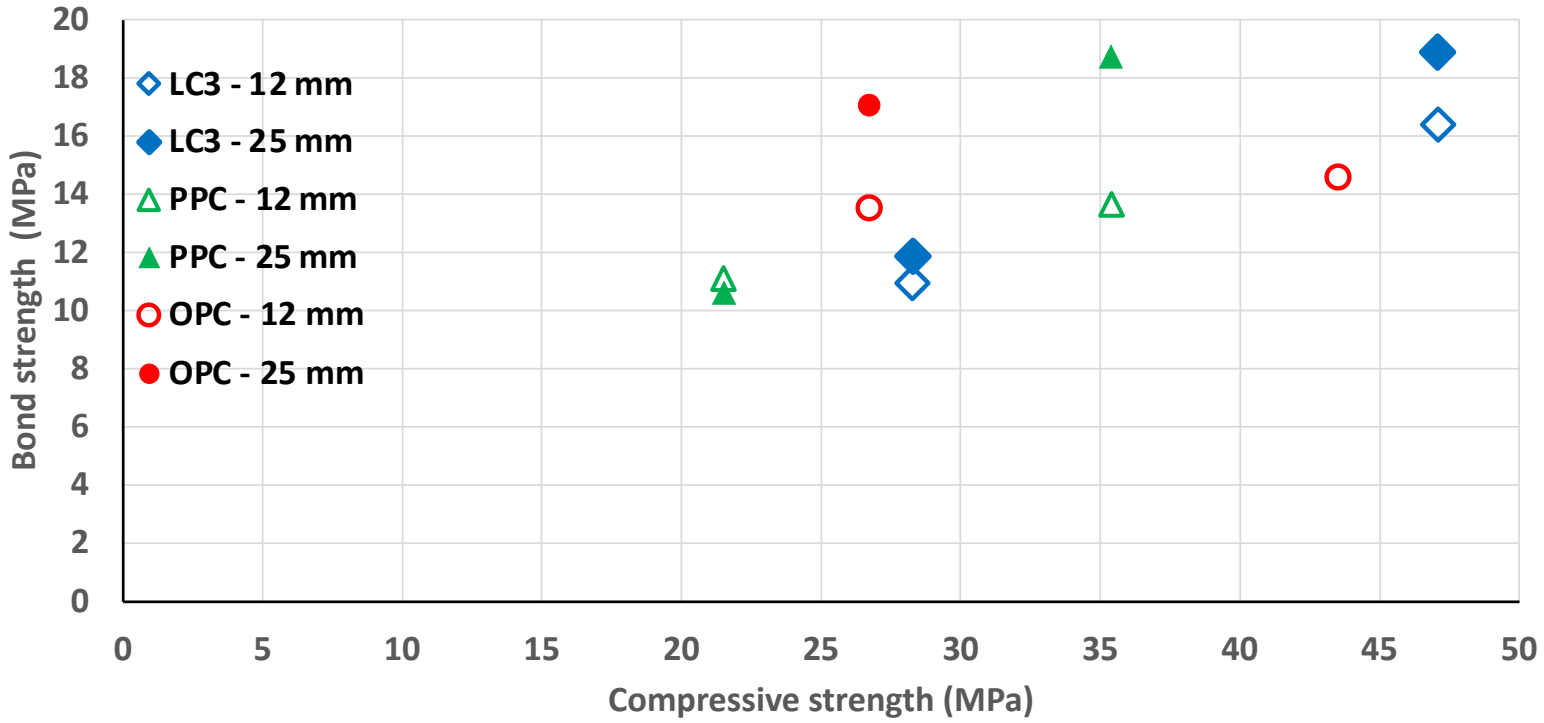
Harsh Vardhan et al. 2020

Good quality low-tech concrete

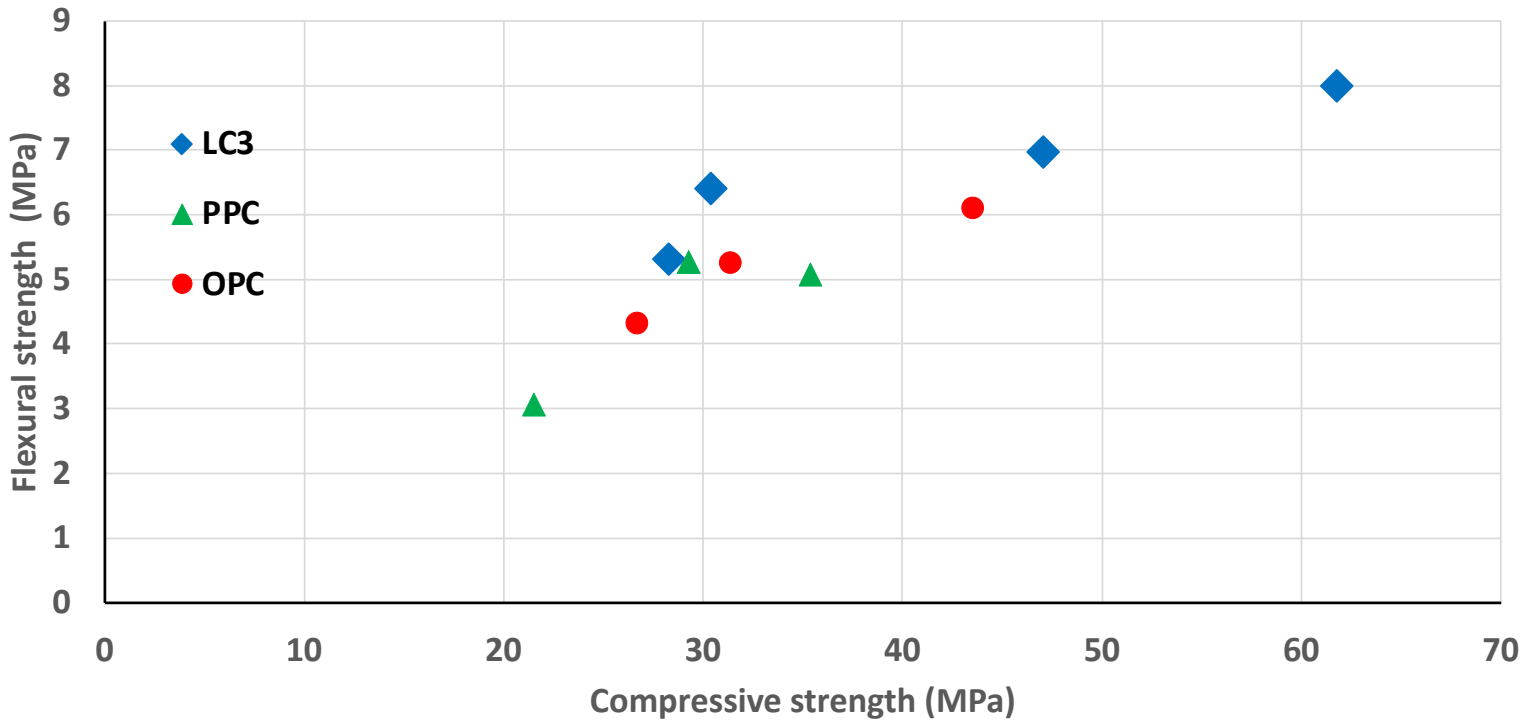


Impact Engineering properties

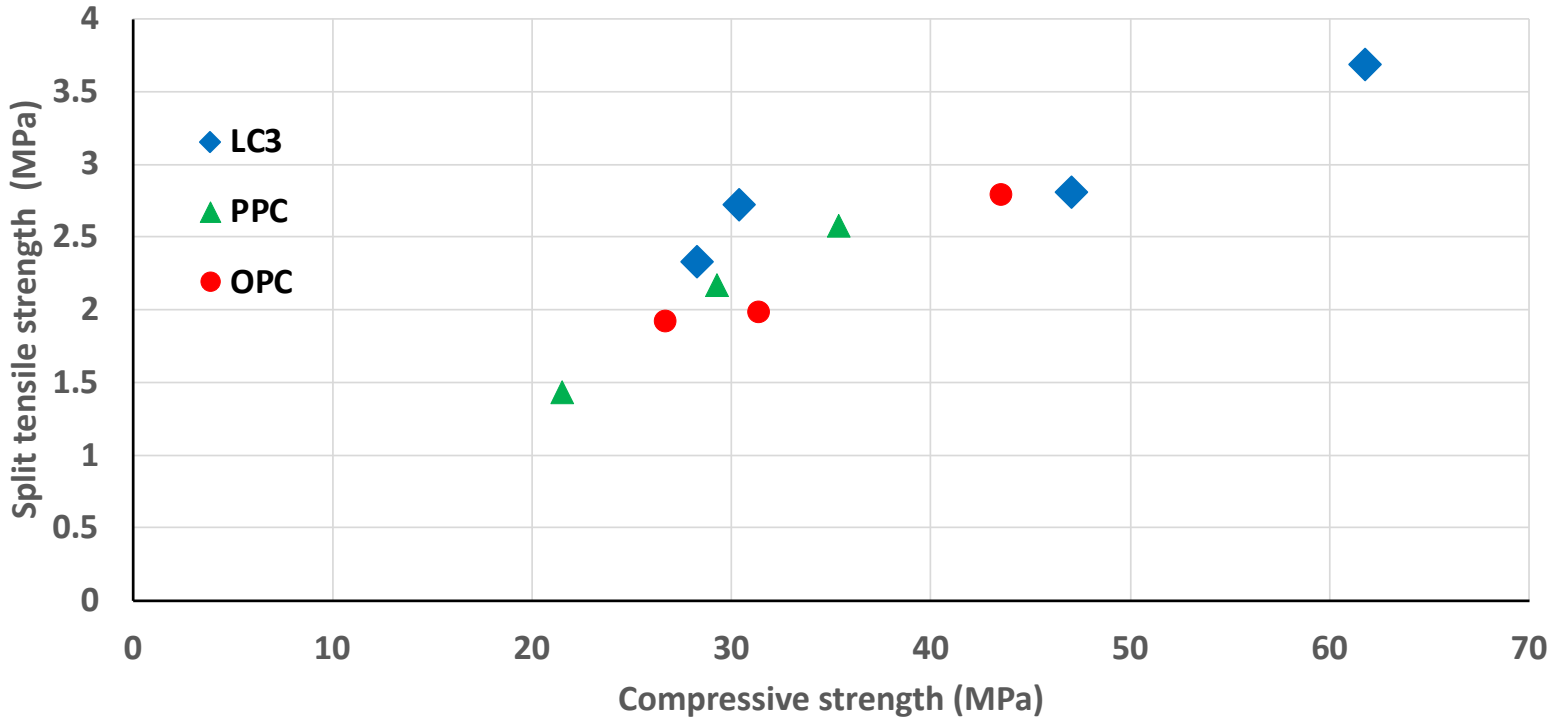
Bond with reinforcement



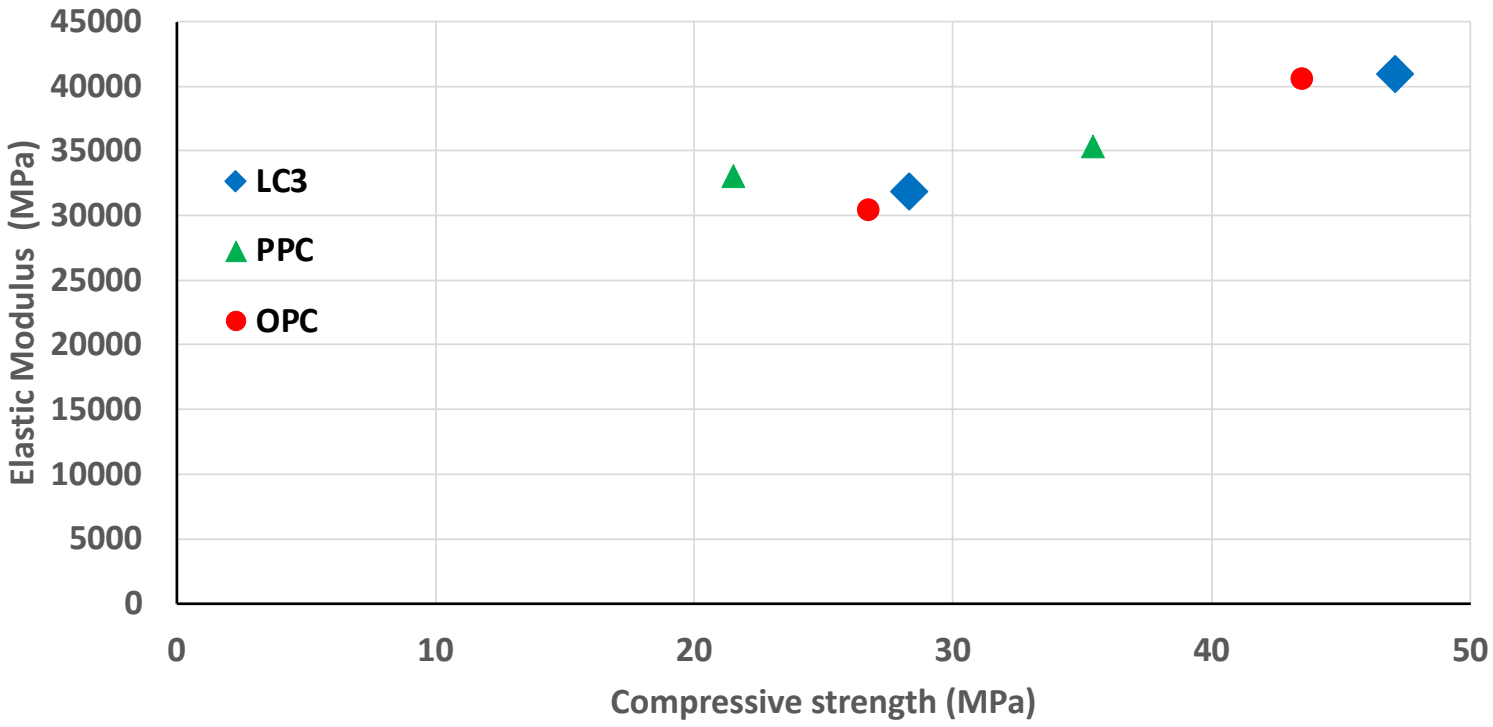
Flexural strength



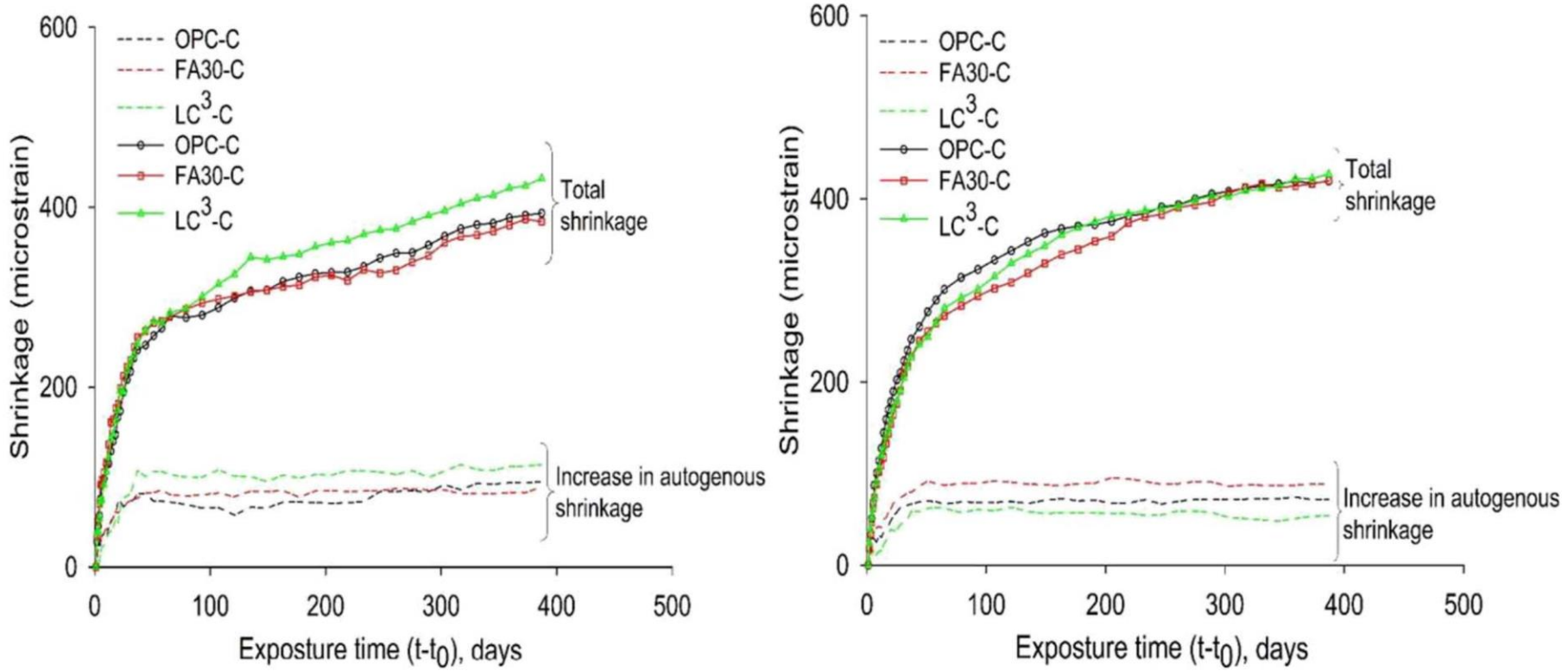
Split tensile strength



Elastic Modulus

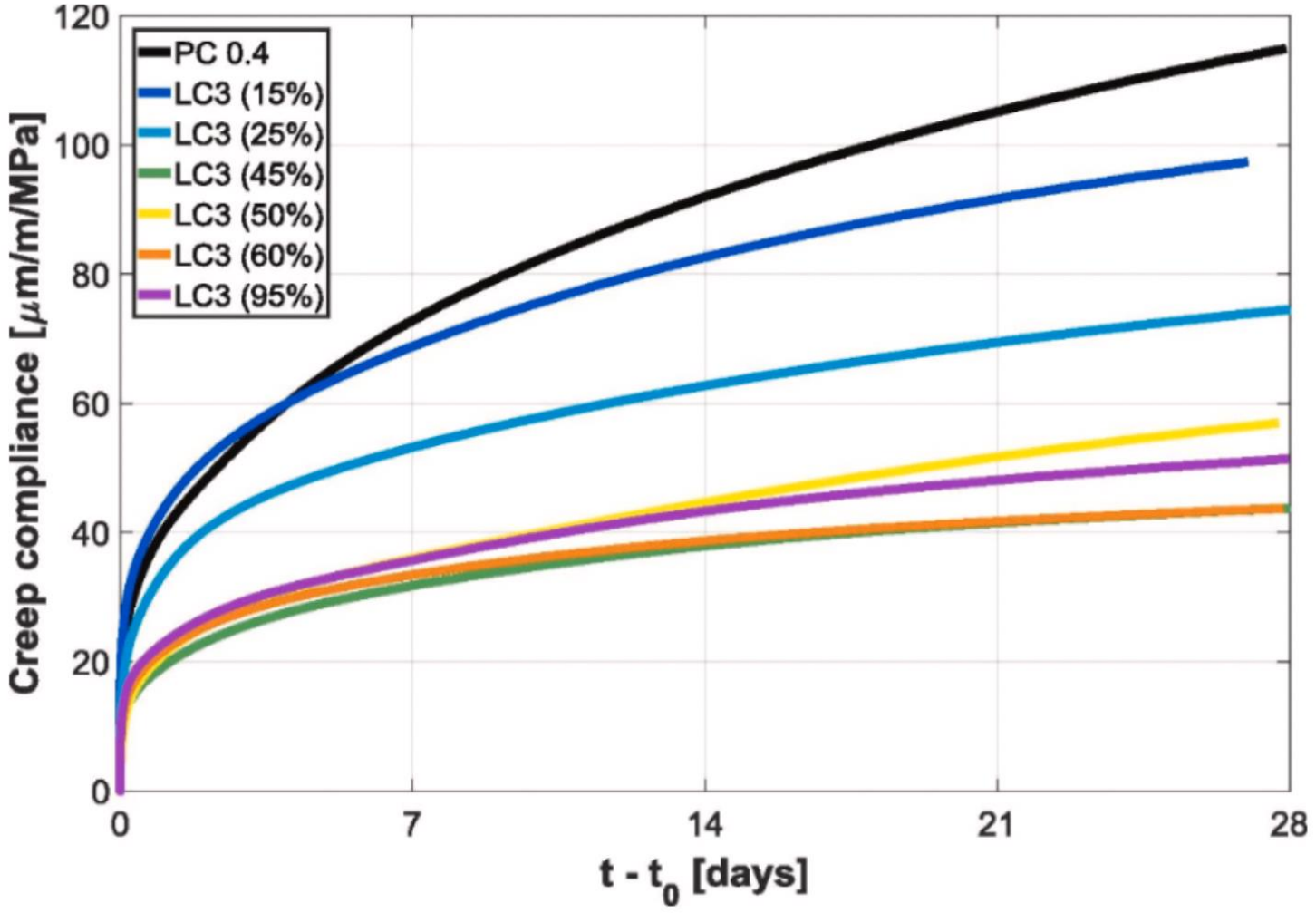


Shrinkage of concrete



Dhandapani at al. 2018

Creep, significantly lower



Ston et al. 2019

But no evidence
of increased cracking

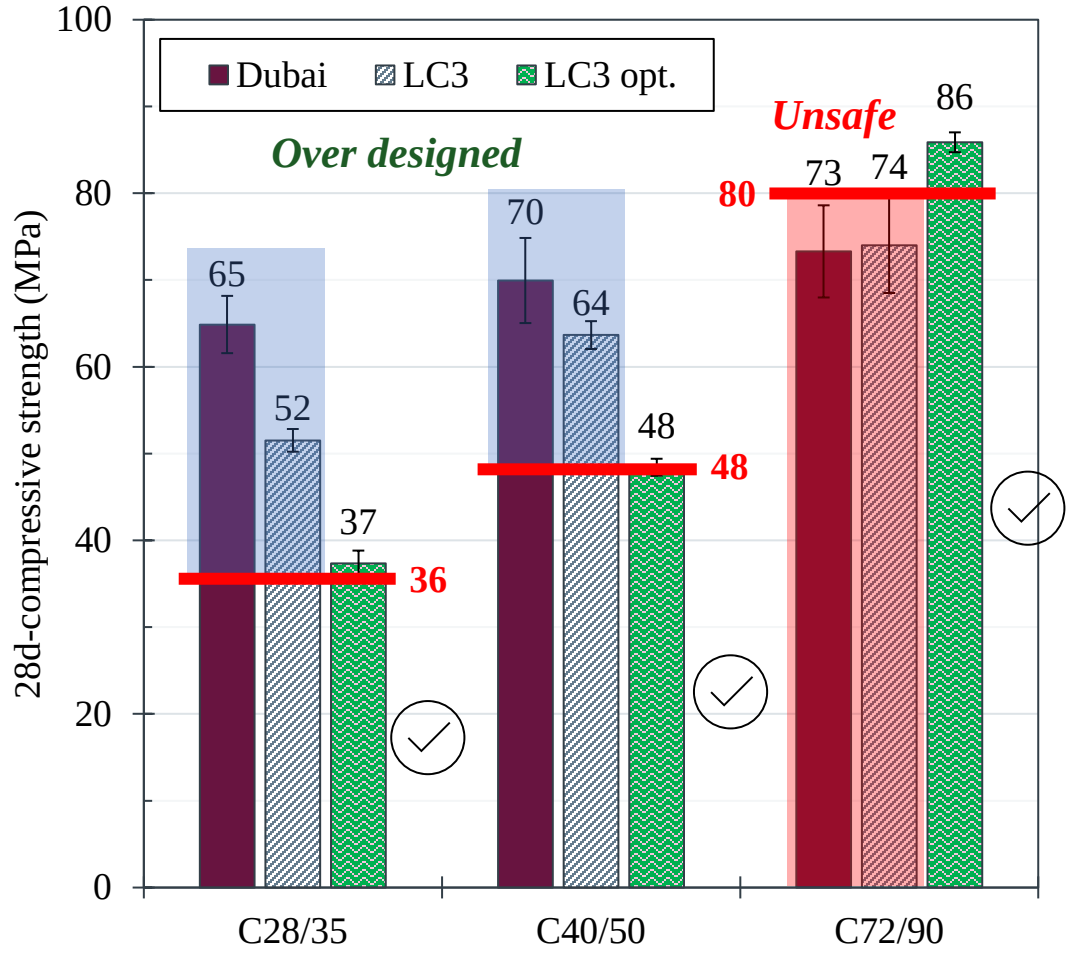
Comparison of LC3 concrete with concretes prescribed in Dubai

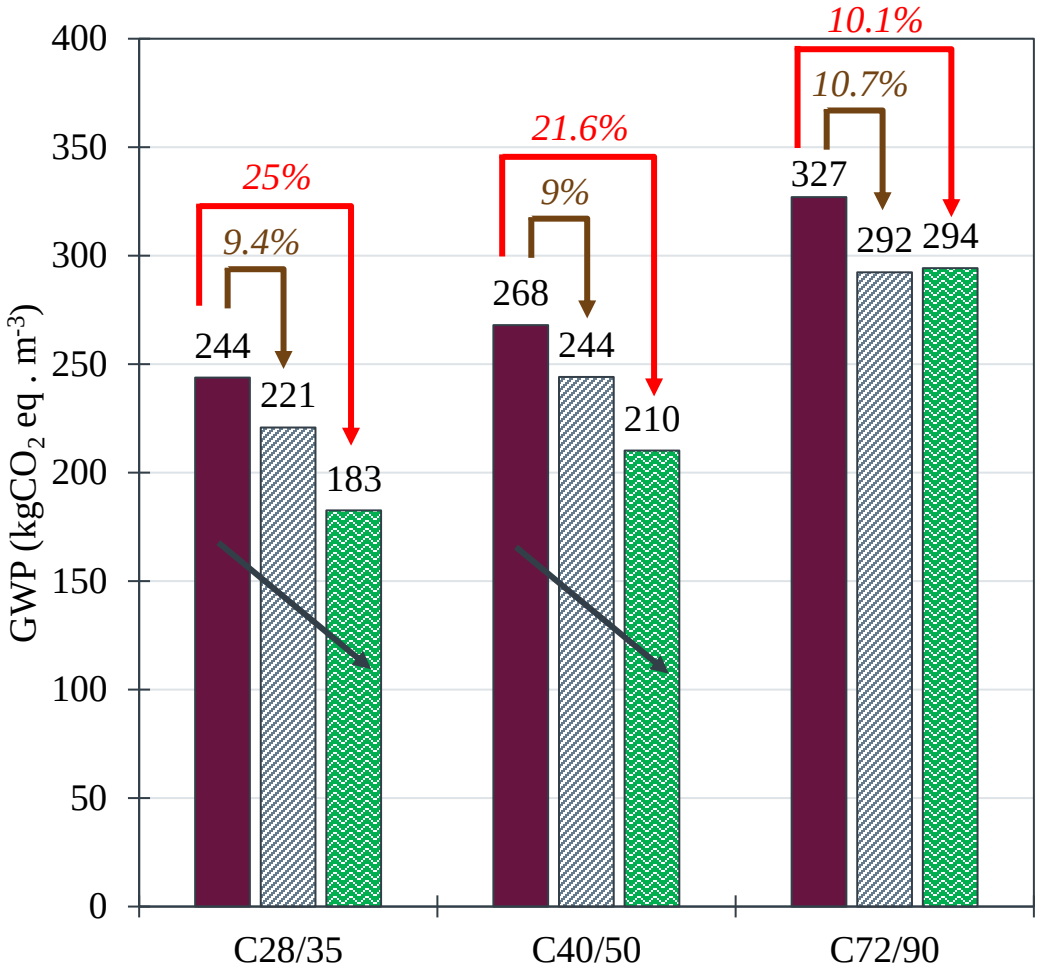
A report on the Dubai Building Code for sustainable concrete - 2021 edition

Mix designs

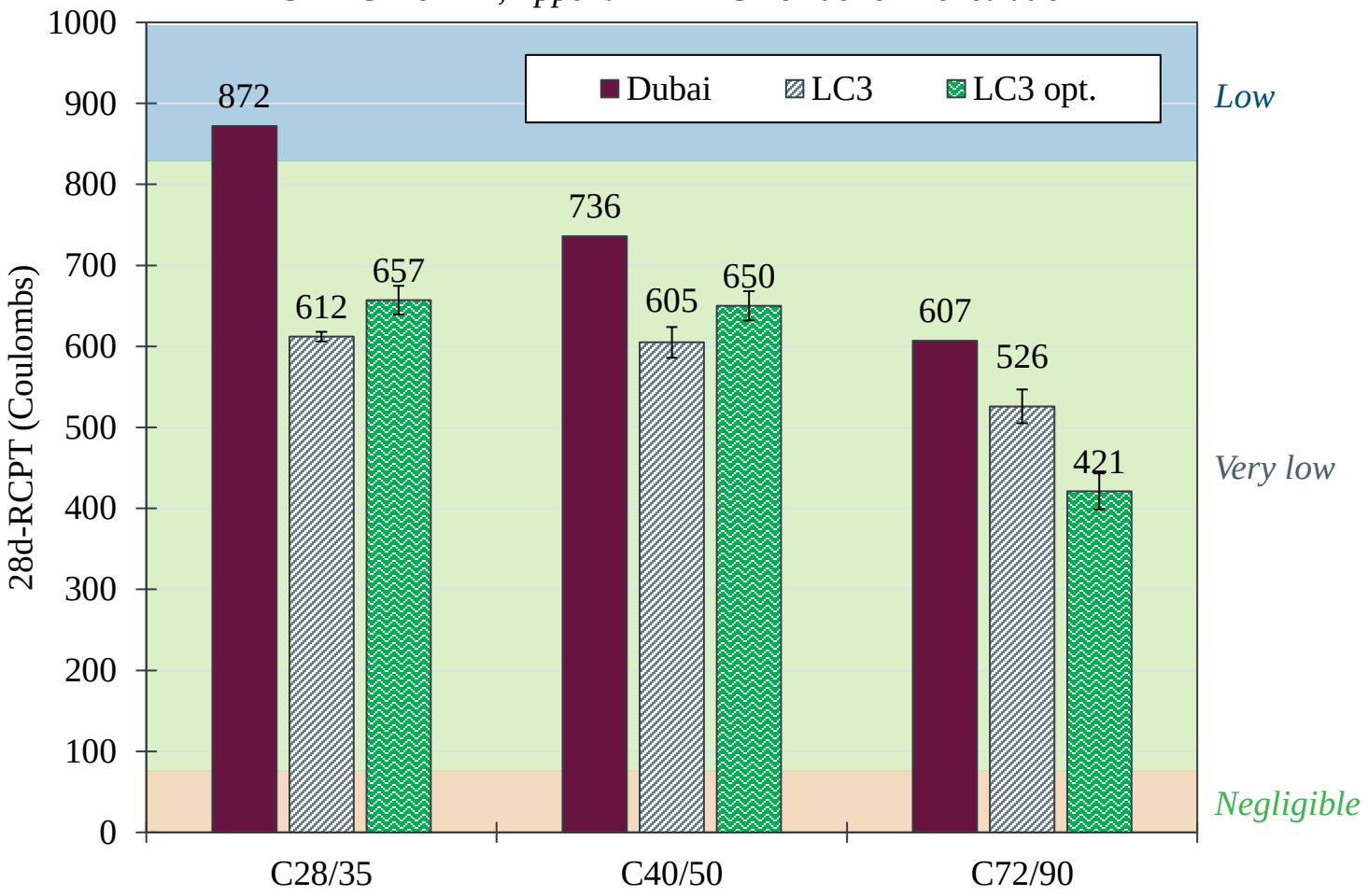
Strength class		C28/35			C40/50			C72/90	
Materials (kg/m³)	Dubai	LC^3	LC^3 opt.	Dubai	LC^3	LC^3 opt.	Dubai	LC^3	LC^3 opt.
Total binder	**380**	**380**	**325**	**420**	**420**	**375**	**510**	**510**	**510**
GGBS ratio	36%			36%			26%		
SF ratio		55kg (*15%*)			45kg (*11%*)		8%		
w/b ratio	**0.42**	**0.42**	**0.61**	**0.36**	**0.36**	**0.48**	**0.29**	**0.29**	**0.26**
SP (%)	0.50	1.56	0.20	0.50	1.97	0.50	0.75	1.97	2.50
Slump test (mm)	10	-	**100**	10	-	**75**	10	-	**10**

Compressive strength and GWP





ASTM C1202-12, Appendix X1 – Chloride Ion Penetration

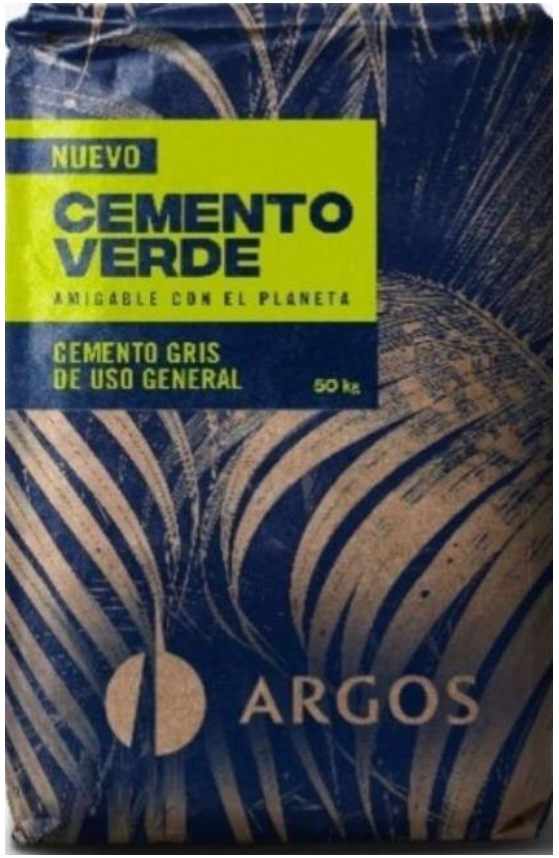


Building with LC^3

LC^3 is already produced industrially in major plants around the world and used in large-scale building and infrastructure.

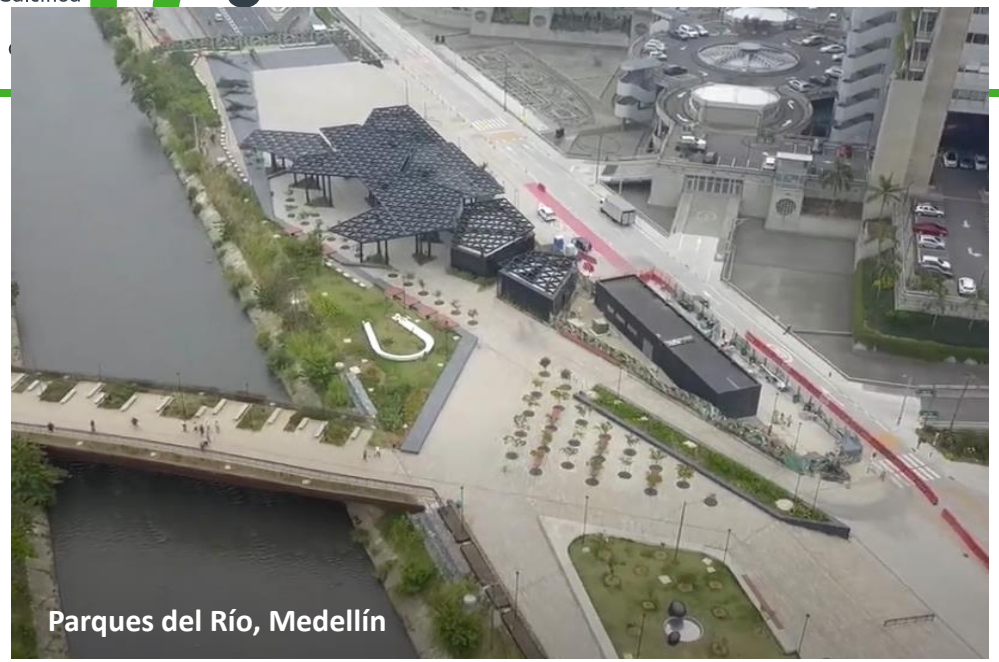
A few examples in Latin America and Europe.

Industrial projects: Cemento Verde ARGOS, Colombia

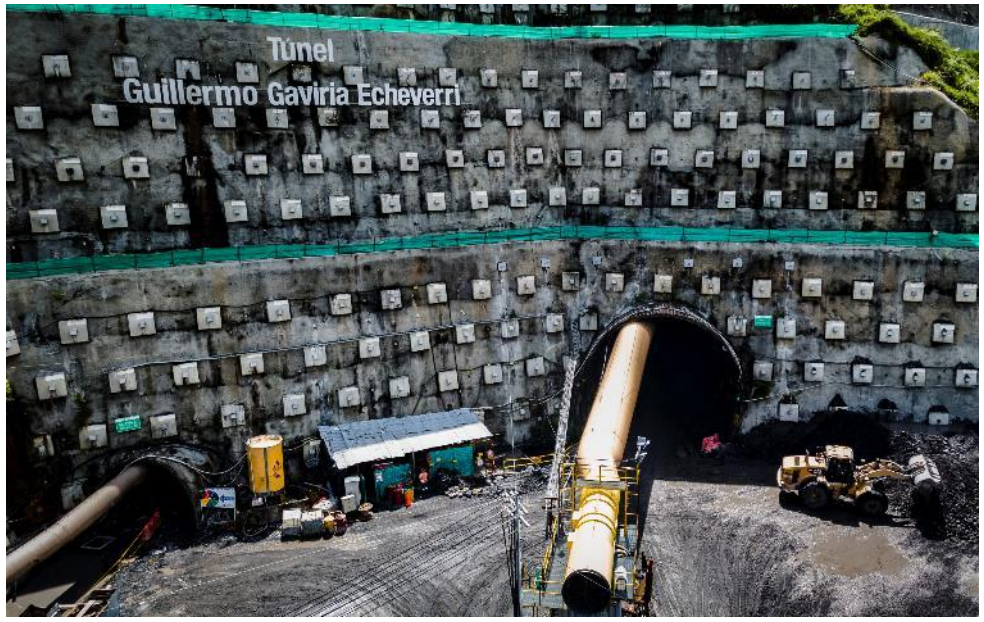


Courtesy of Cementos Argos

Puente Cauca, Columbia


Parques del Río, Medellín

Centro Comercial Arkadia, Medellín

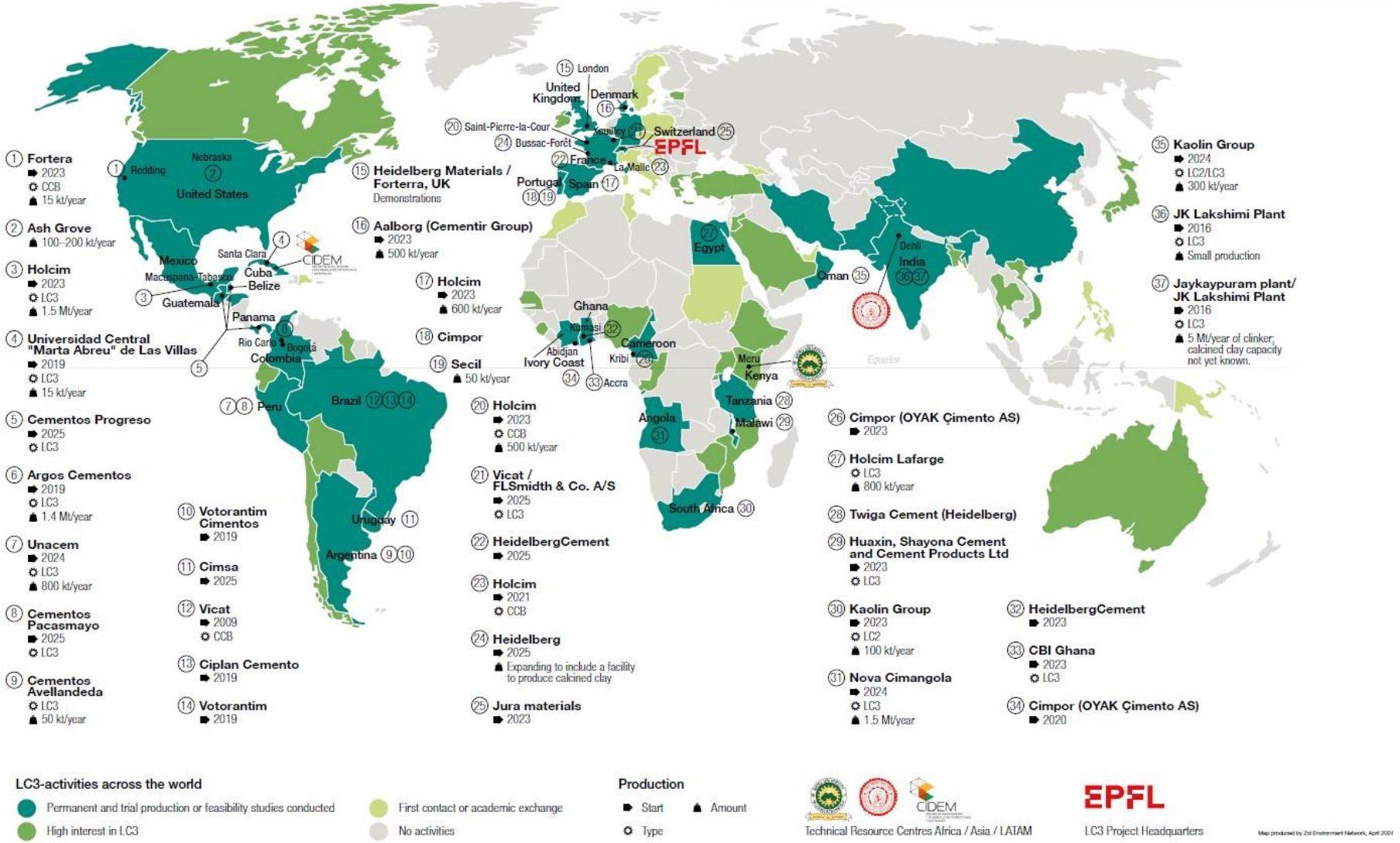


Courtesy of Cementos Argos

Europe

- Holcim's ECOPlanet LC^3-type cement used for constructing a marina in Marseille, France for the 2024 Olympics.
- Tilia Tower©, Switzerland is an ambitious and sustainable high-rise building.
  - Slabs and internal walls are in LC^3 from Jura Ciment
  - External façade in wood

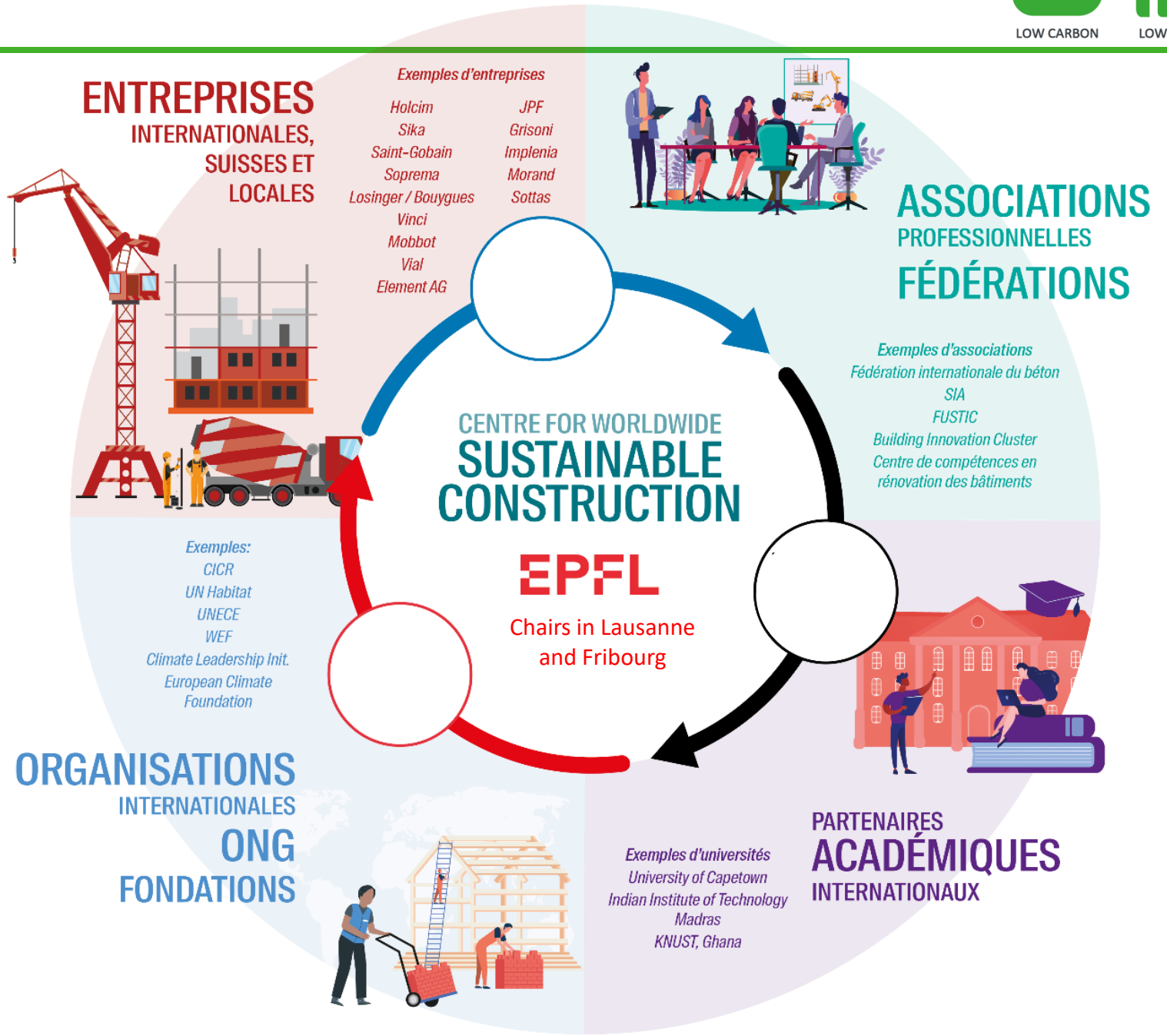
Mapping Calcined Clay Plants



Concluding remarks

- ✓ Substantial reductions in CO_2 are possible
  - ✓ At cement level by increasing SCM substitution
  - ✓ At concrete level by minimising cement content
  - ✓ At structure level
- ✓ All of the above will also lower cost
- ✓ Remainder CO_2 can only be dealt with by carbon capture and storage at a high cost, infrastructure not in place.
- ✓ Calcined clays are the only realistic option for extending the use SCMs
- ✓ Can be done FAST and at SCALE

CWSC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Sika
Saint-Gobain
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More information on: www.LC3.ch

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