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Swiss Agency for Development
and Cooperation SDC

The Indian experience in the development of Limestone Calcined Clay Cement

Shashank Bishnoi and Soumen Maity

TARA

INDIAN INSTITUTE OF TECHNOLOGY MADRAS

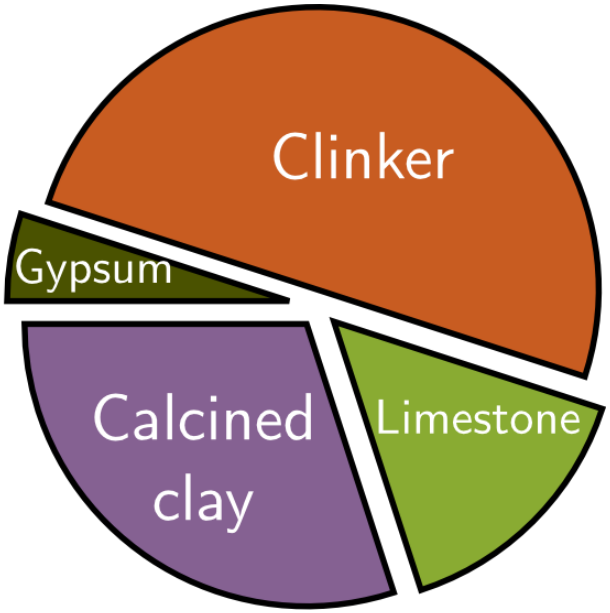
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

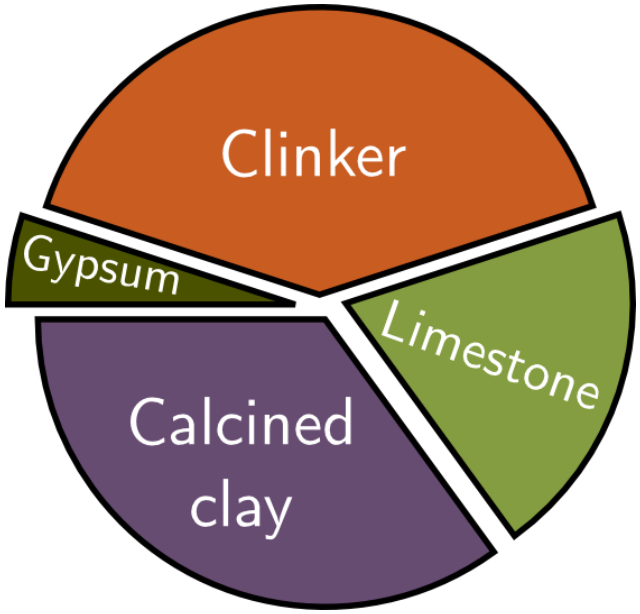
ज्ञानम् परमम् ध्येयम्

भारतीय प्रौद्योगिकी संस्थान दिल्ली

INDIAN INSTITUTE OF TECHNOLOGY DELHI

What is LC^3?





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Limestone Calcined Clay Cement LC3

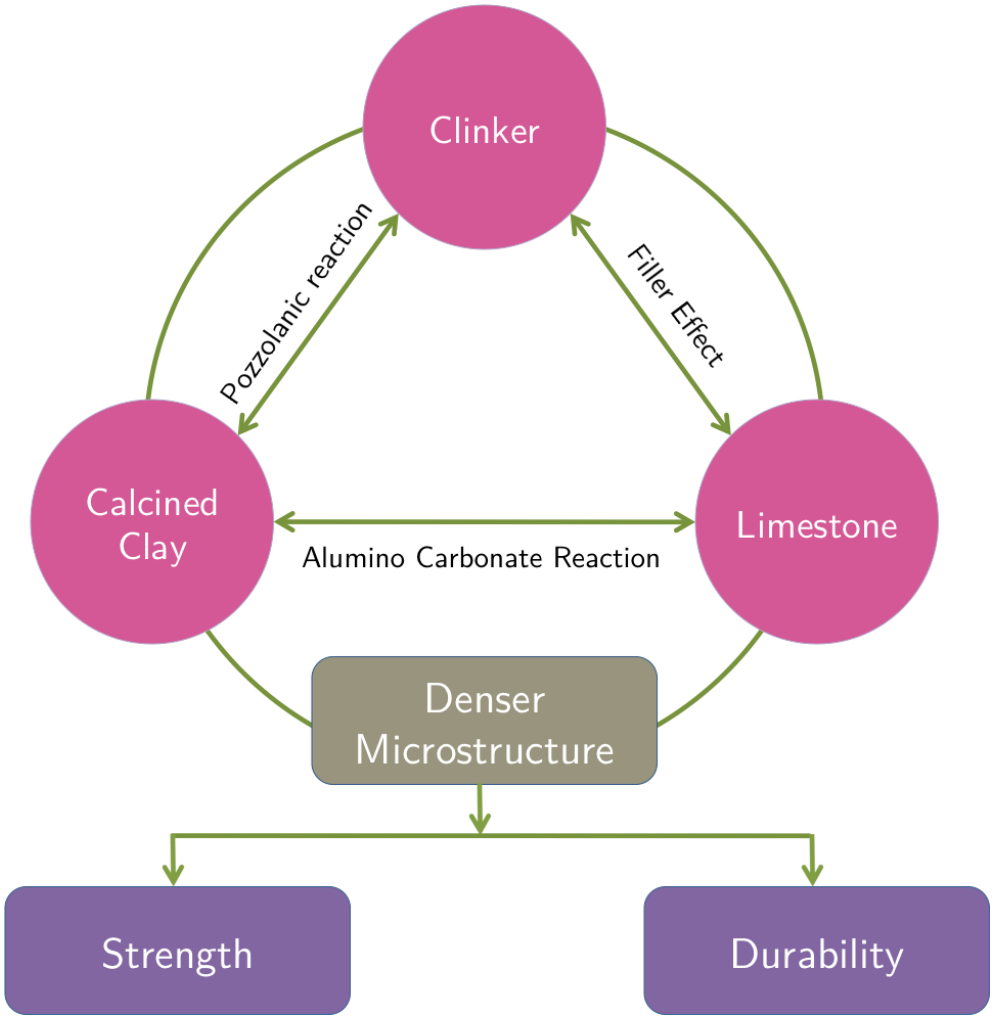
Limestone Calcined Clay Cement

- Objective: Support early uptake of LC^3
  - Convince industry & develop standard
- Large multi-partner project
  - Funded by Swiss Agency for Development and Cooperation
  - IIT Delhi, IIT Madras, IIT Bombay, TARA, EPFL Switzerland, CIDEM Cuba
- Scientifically study:
  - Material availability, Ecology & Economy
  - Workability, Mechanical properties & Durability
  - Pilot production, pilot construction & monitoring

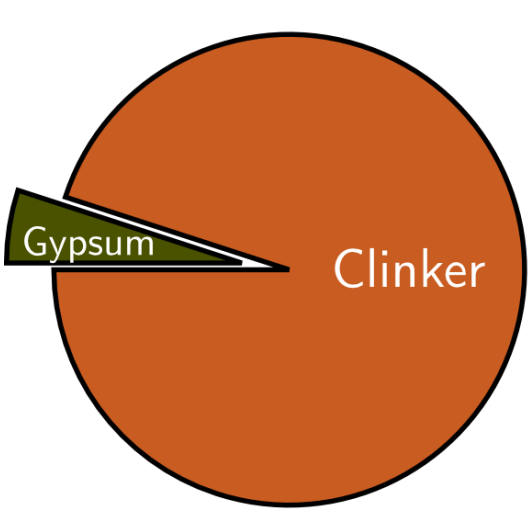
What do clay and limestone do?

- Calcined clay is known to have a pozzolanic reaction
- Limestone acts as filler
  - Improves rheology,
  - Finer microstructure
- Calcined clay + Limestone:
  - $(Al_2O_3) : 2\cdot(SiO_2)$ + $CaCO_3$
  - Al_2O_3 + CaCO3 + Ca^{2+} + OH^- ⇨ C4ACH11

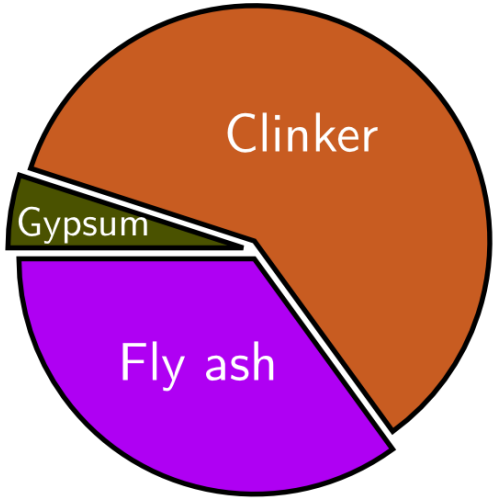
Synergy



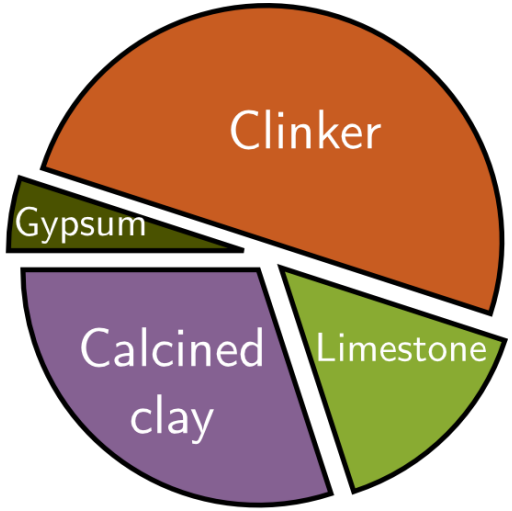
LC^3: The Indian scenario



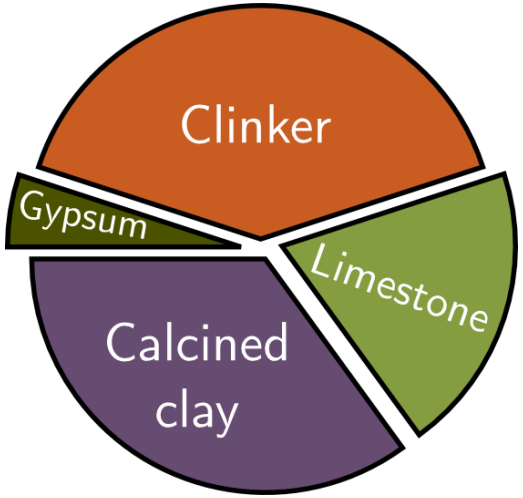
OPC



PPC



LC^3



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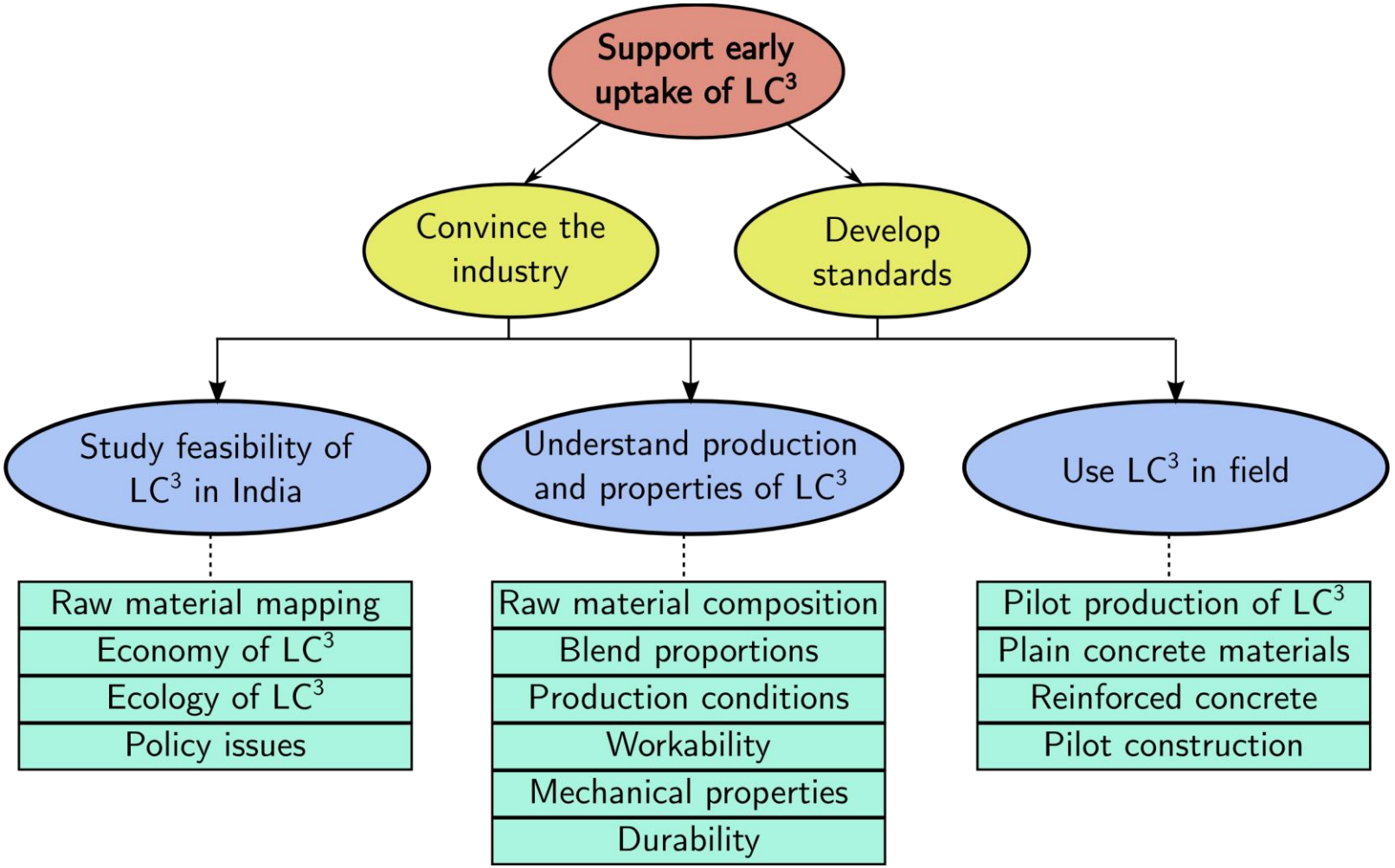
Limestone Calcined Clay Cement LC^3

Clinker factor

- Average clinker factor: 0.70 (2014)
  - Target 0.58 by 2050
- Fly ash
  - Limited to 35% by code
  - 173 MMT last year → 600 MMT by 2030
- Slag
  - Limited to 70% by code
  - 22 MMT per year available
- Calcined clay
  - Limited to 25% by code

Project plan



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Limestone Calcined Clay Cement LC3

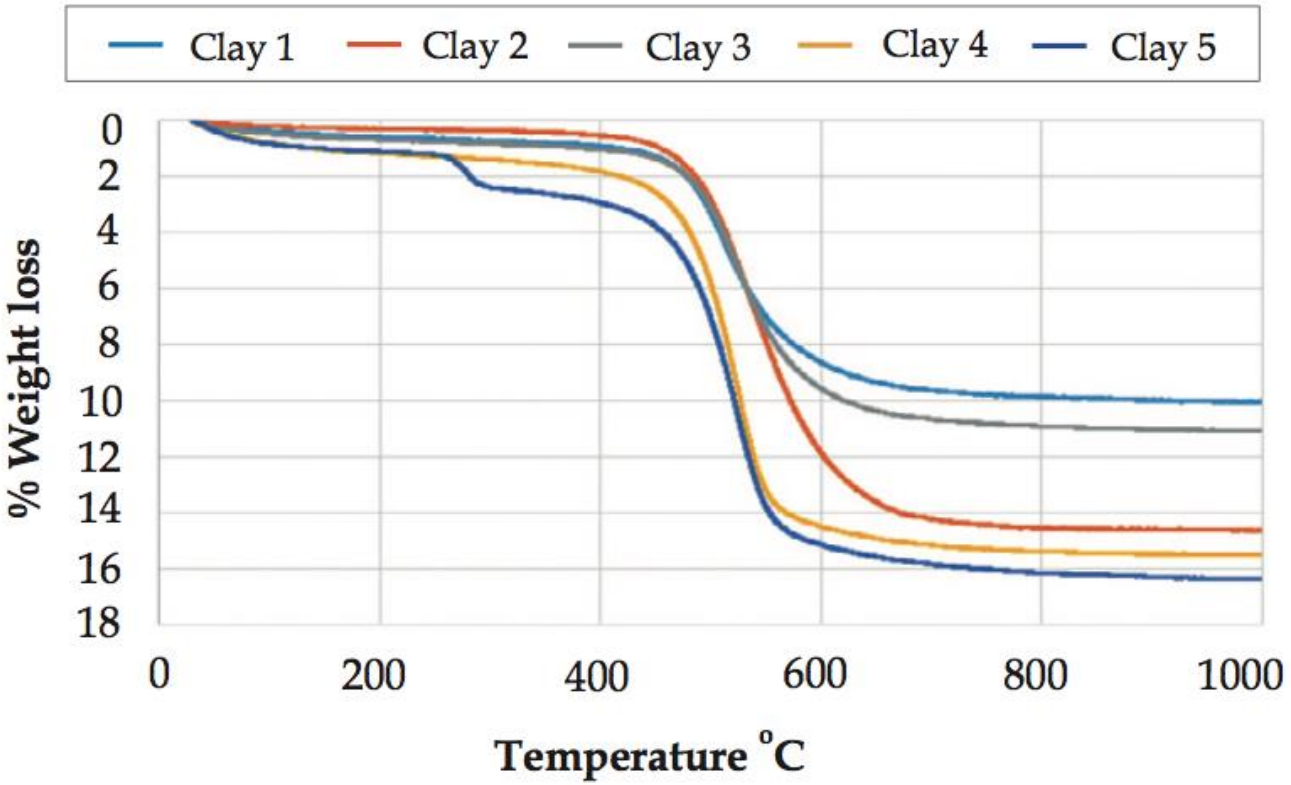
Advantages of LC^3

- Lower clinker factor
  - 30% less emissions than OPC, 11% less than PPC
  - Faster growth, lower capital investment
- Better early strength & good 28 day strength
- Can utilise low grade limestone
  - Additional limestone not calcined – dolomitic limestone works
- High grade clay not needed

Current understanding: Clay

- Large deposits of clays available in India
  - Required kaolinite content: 50% to 60%
  - Iron content not an issue
- Calcination
  - Dehydroxyllation of kaolinite, completed by 800° C
  - Mulletisation should not occur
  - Petcoke can be used as fuel
- Fineness
  - Very fine clay increases water demand
- Characterisation using TGA & XRD

TGA analysis of clays



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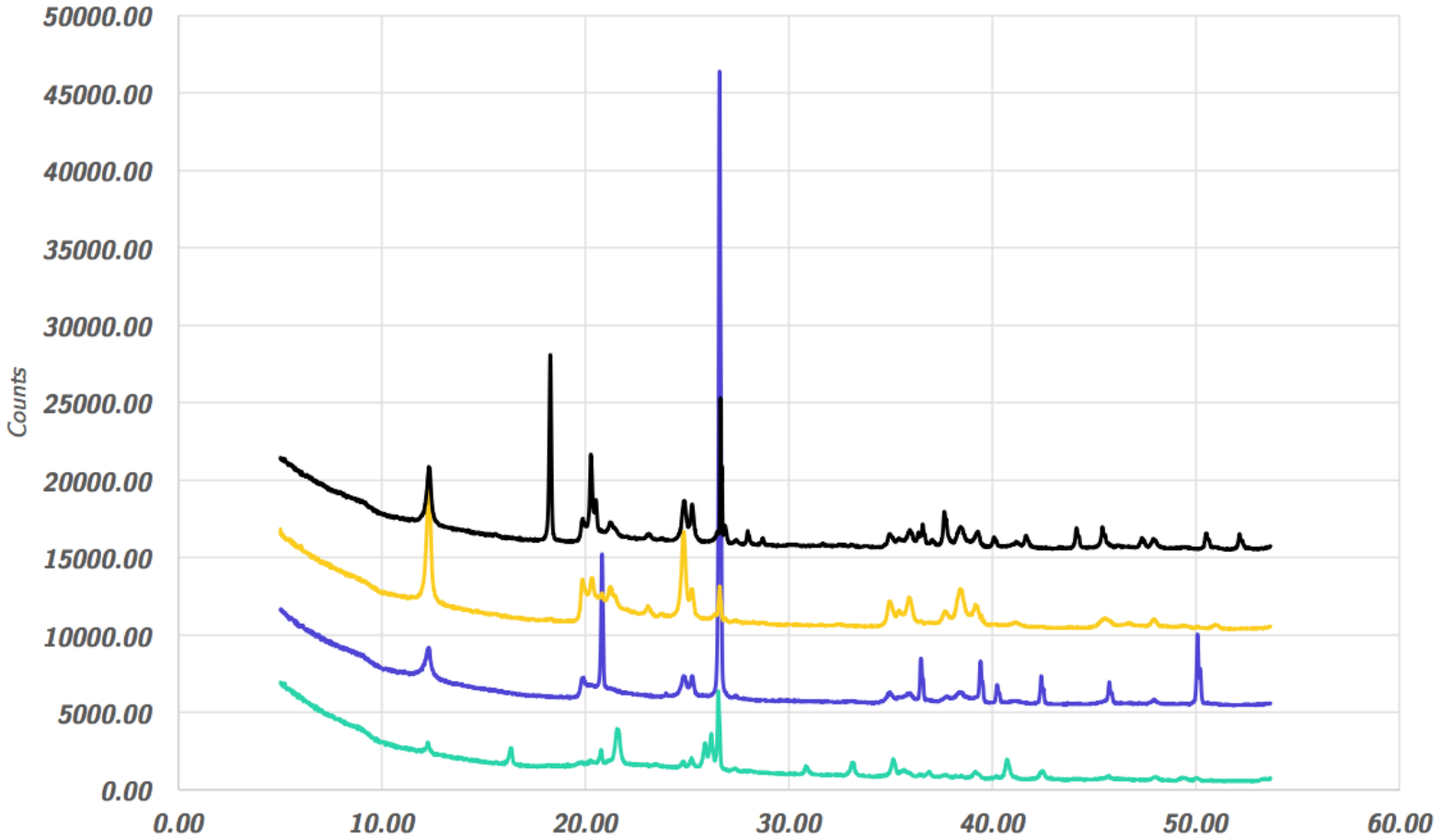
Limestone Calcined Clay Cement LC3

XRD analysis of clays



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Limestone Calcined Clay Cement LC3

XRD analysis of calcined clays

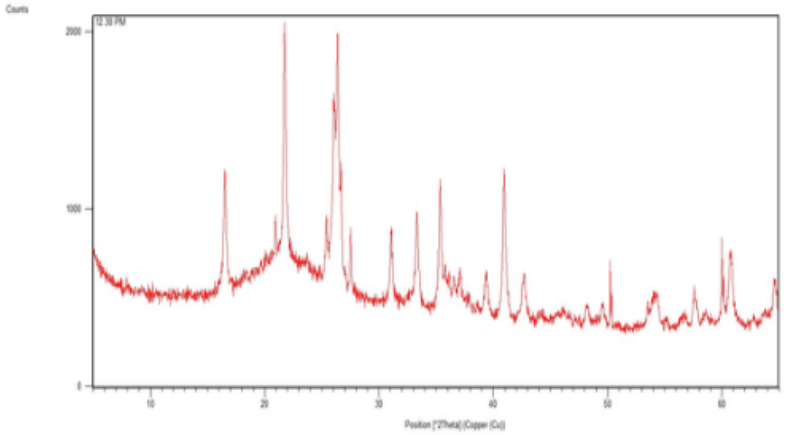

Fig 4 - XRD of clay sample at 12:30 PM

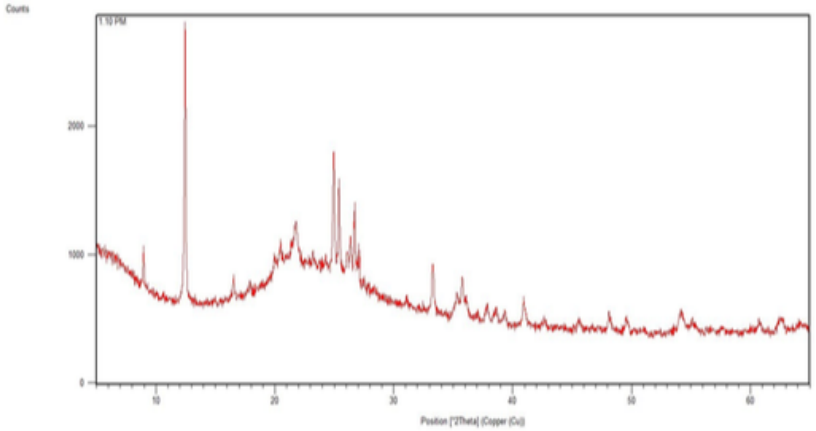

Fig 6 - XRD of clay sample at 1:10 PM

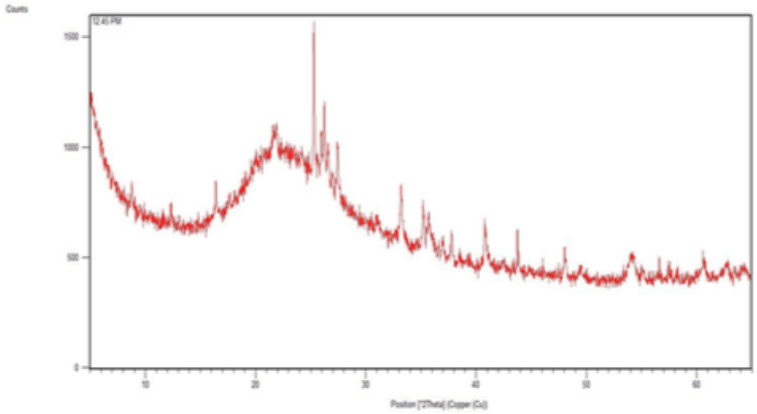

Fig 5 - XRD of clay sample at 12:45 PM

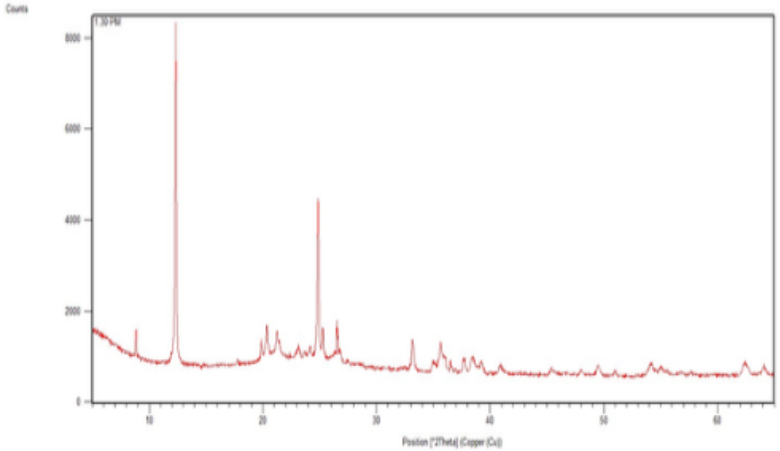

Fig 6 - XRD of clay sample at 1:30 PM

Calcination: static vs. rotary

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Limestone Calcined Clay Cement LC3

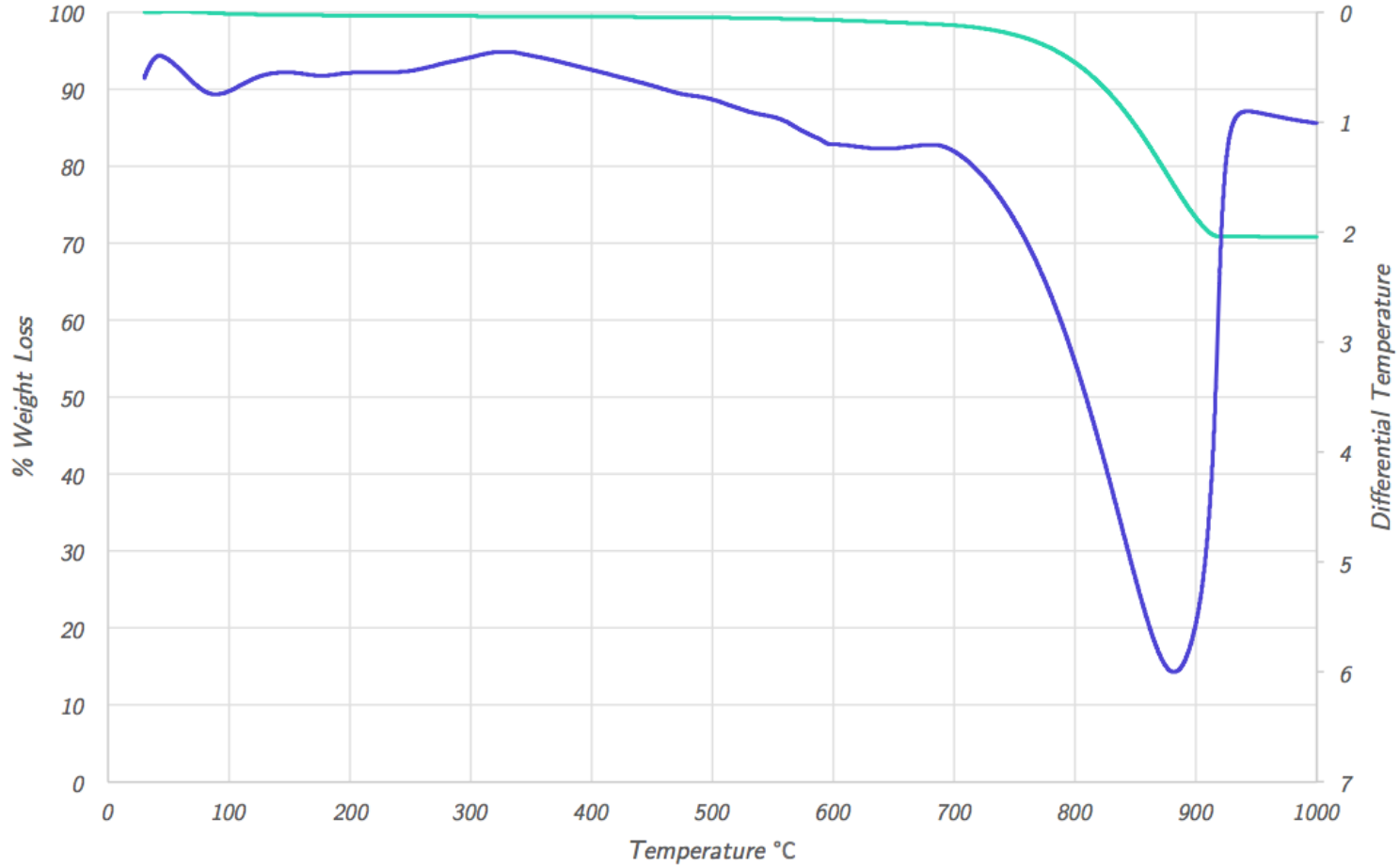
Current understanding: Limestone

- Composition: down to 35% CaO content
  - Dolomitic limestone works
  - Siliceous limestone works
  - Stone wastes available
- Improves workability
- Characterisation using TGA & XRD

Low grade limestone

Stone wastes: Marble

TGA analysis of limestone



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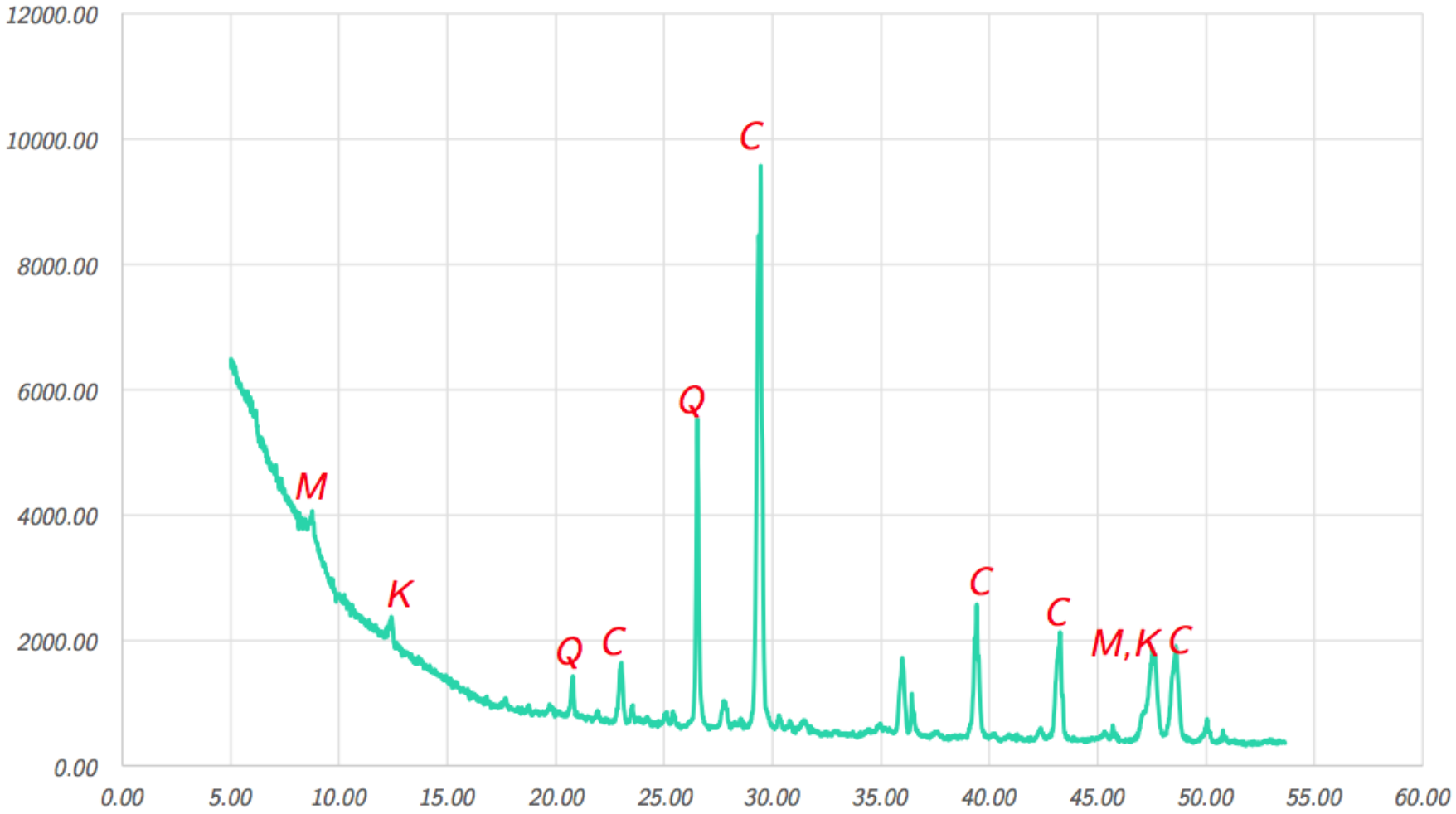
Limestone Calcined Clay Cement LC3

XRD analysis of limestone



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Limestone Calcined Clay Cement LC3

Current understanding: production

- Inter-grinding of clay with clinker a challenge
- Pre-grinding of clinker may work better
  - Potential for LC^2

Grinding: open vs. closed circuit

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Limestone Calcined Clay Cement LC3

Current understanding: performance

- Strength similar or better than OPC
- Good durability under conditions studied: lower permeability
- Water-demand can be higher than OPC and PPC

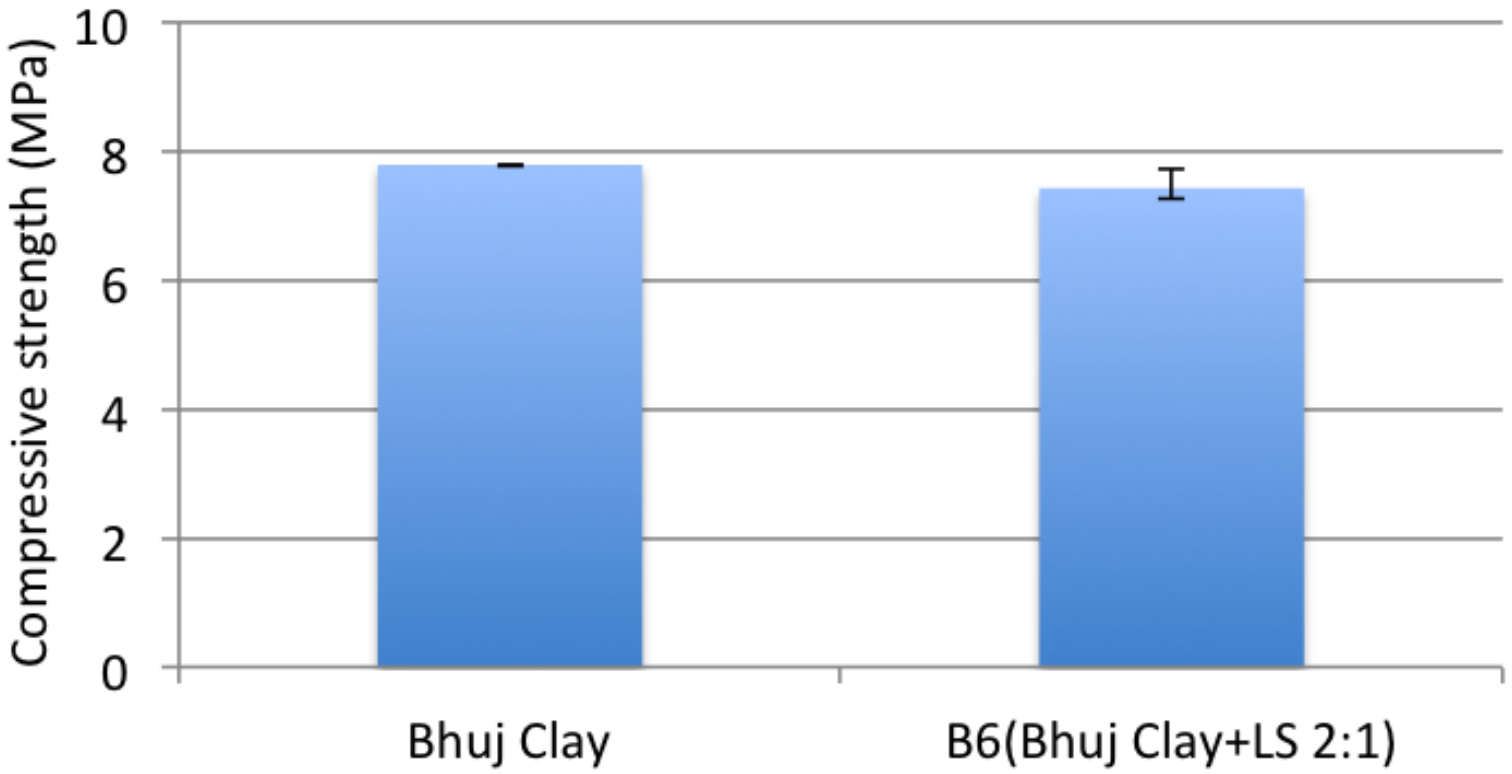
Scientific studies

- Composition
- Strength
- Long term mechanics
- Workability
- Durability
- Economics
- Ecology
- Resources

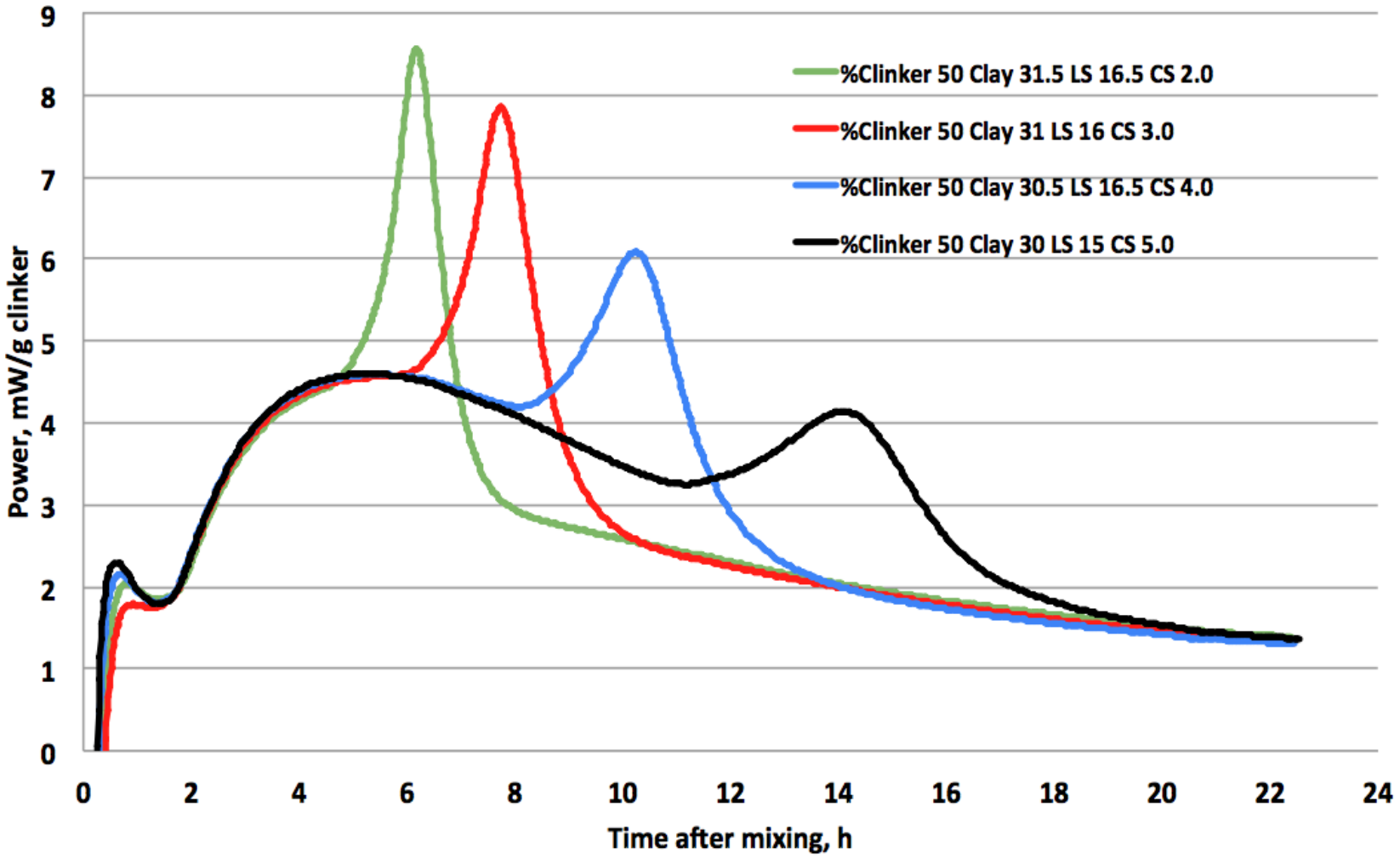
Lime reactivity test (IS1727)

- 5 cm Cubes of calcium hydroxide and SCM prepared
- Water content based on flow
- Strength measured after curing at 50˚C
- e.g. 4.0 MPa required for pozzolanic clay

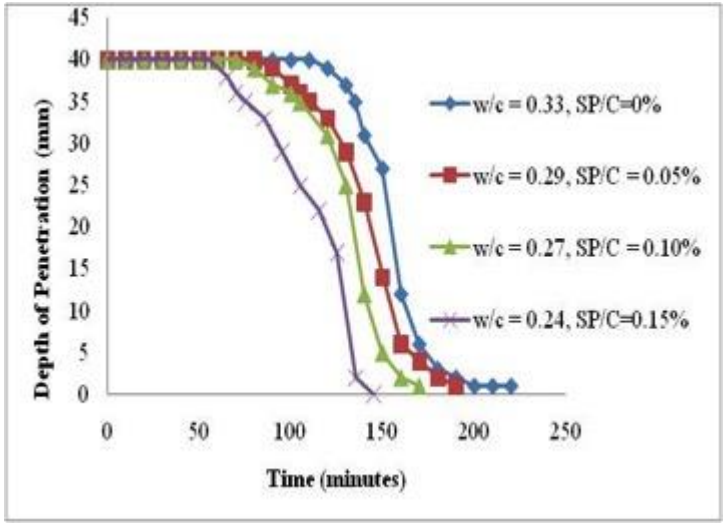
Lime reactivity (IS 1727)



Hydration studies – gypsum content



Rheology



At same consistency, setting of LC3 pastes with superplasticizers is accelerated

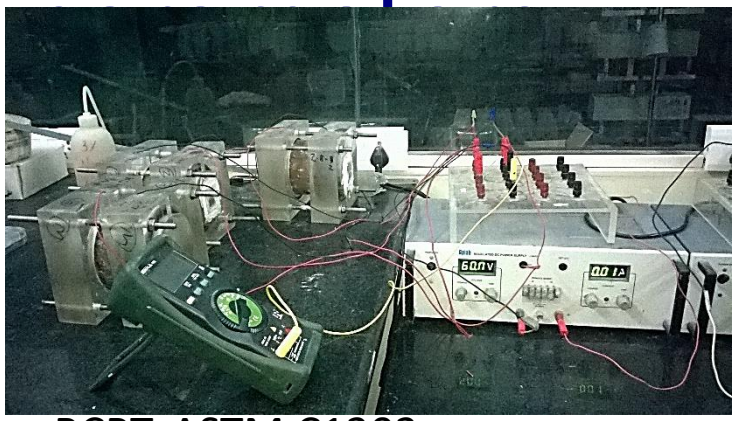
➔ LC3 concretes would not have set retardation issues that are typical of PPC / OPC concretes with superplasticizers

Binder	Saturation sp dosage in paste (sp/b%)	Maximum sp dosage* in concrete (sp/b%)	Slump (mm)		
			Initial	After 30 minutes	After one hour
OPC	0.05%	0.26%	85	35	0
LC^3	0.22%	0.50%	110	35	0
OPC + 30% fly ash (FA30)	0.10%	0.20%	120	20	0

Slump retention behaviour is similar for concretes prepared with SP dosages optimized from paste studies

But more SP dosage required for LC3 concretes

Test methods for durability



RCPT, ASTM C1202

Water Sorptivity test, DI manual, SA

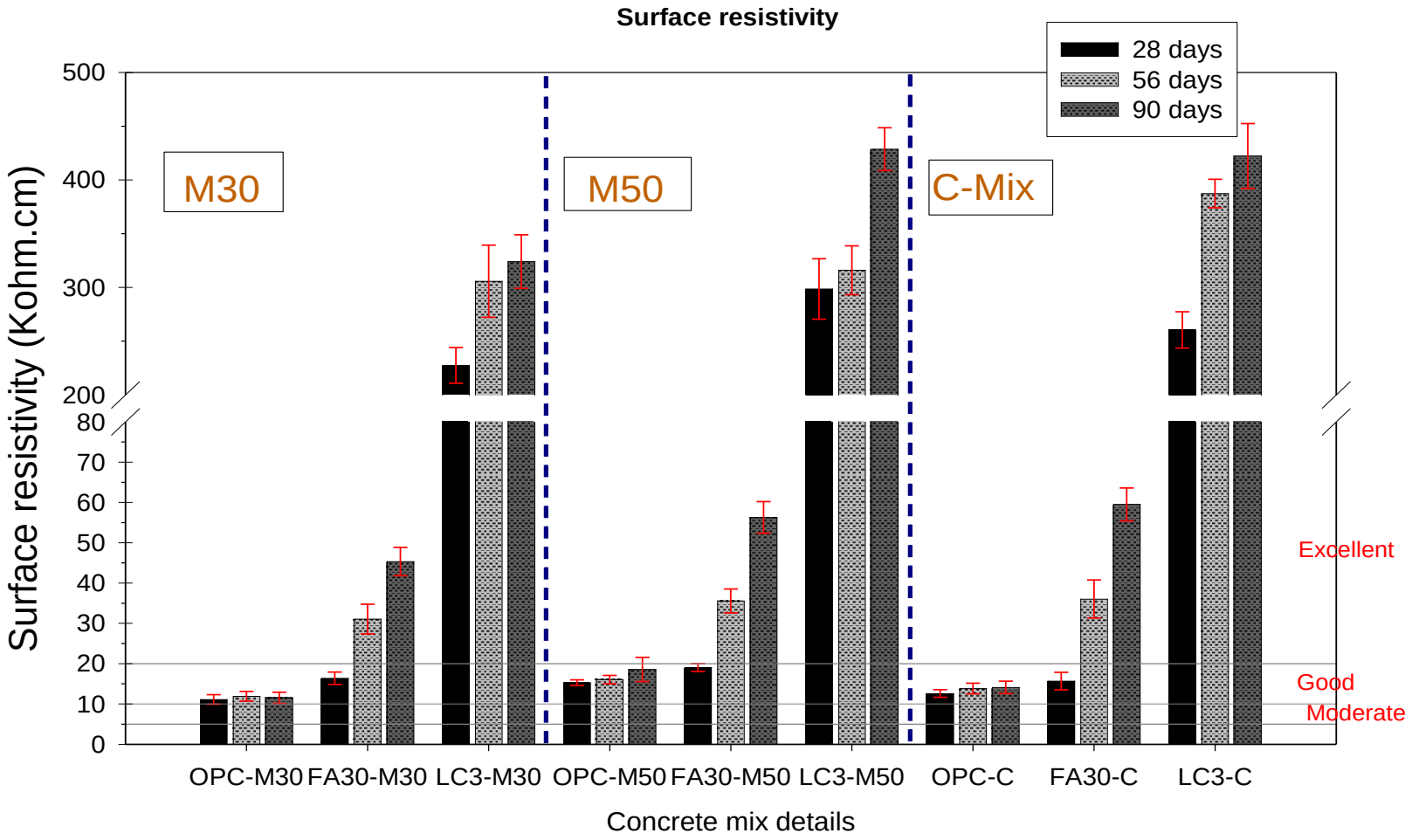
ACMT, NT build 492

Oxygen permeability test, DI manual, SA

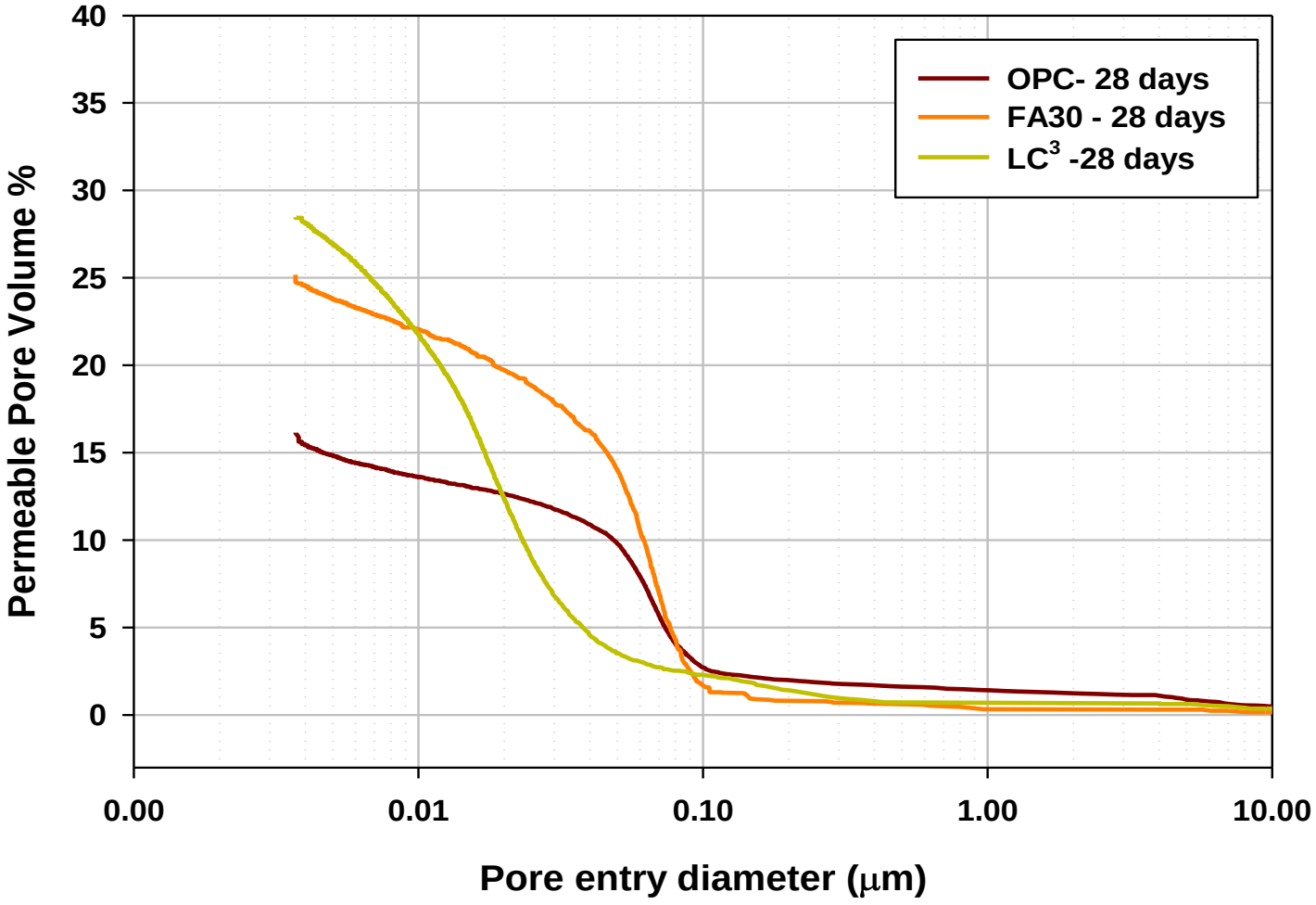
Resistivity measurement

Limestone Calcined Clay Cement LC3

Durability - Surface resistivity



Refined Pore structure in LC^3



Permeable Porosity Vs Pore diameter of OPC, FA30 and LC^3 at 28 days

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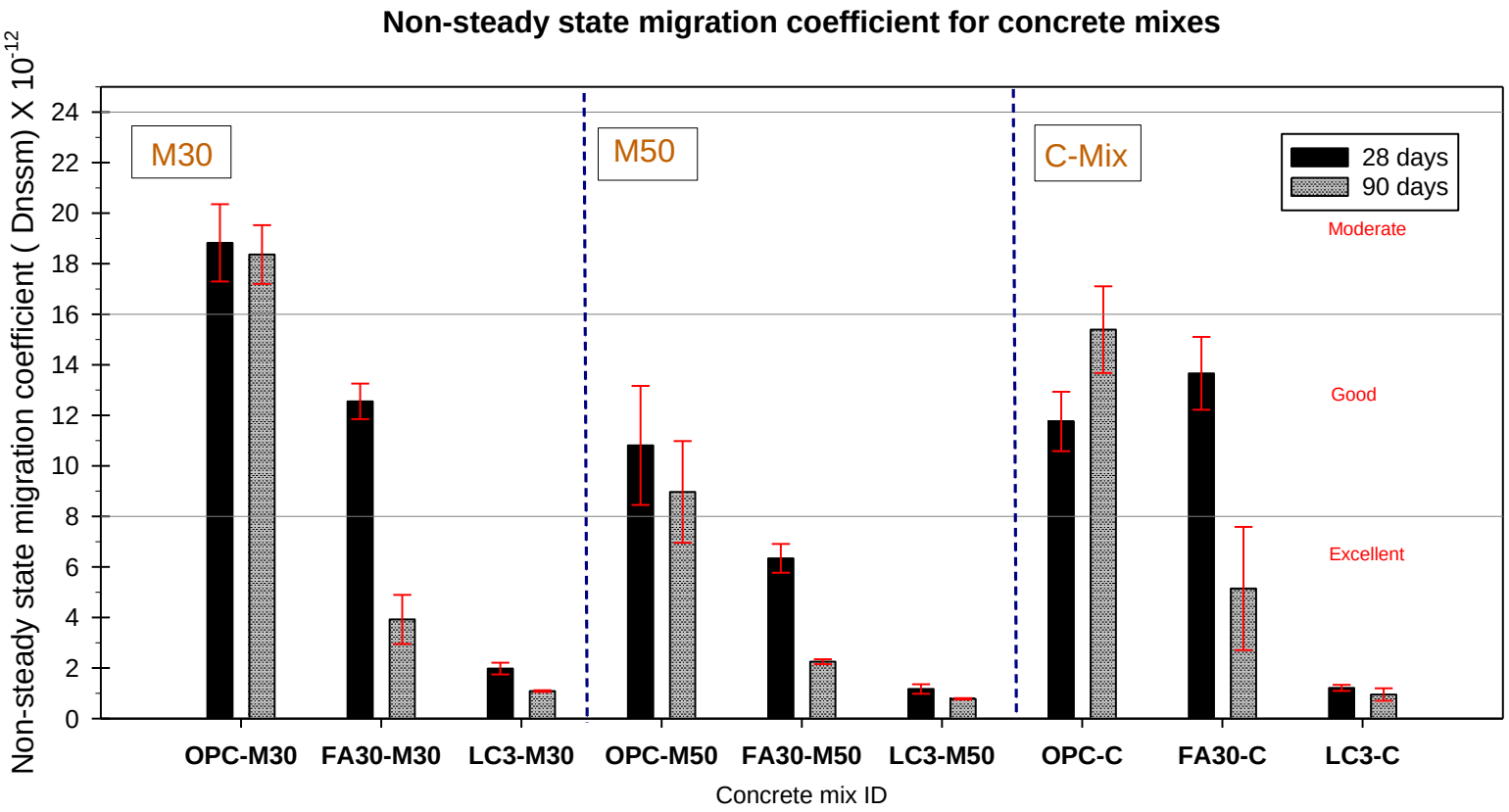
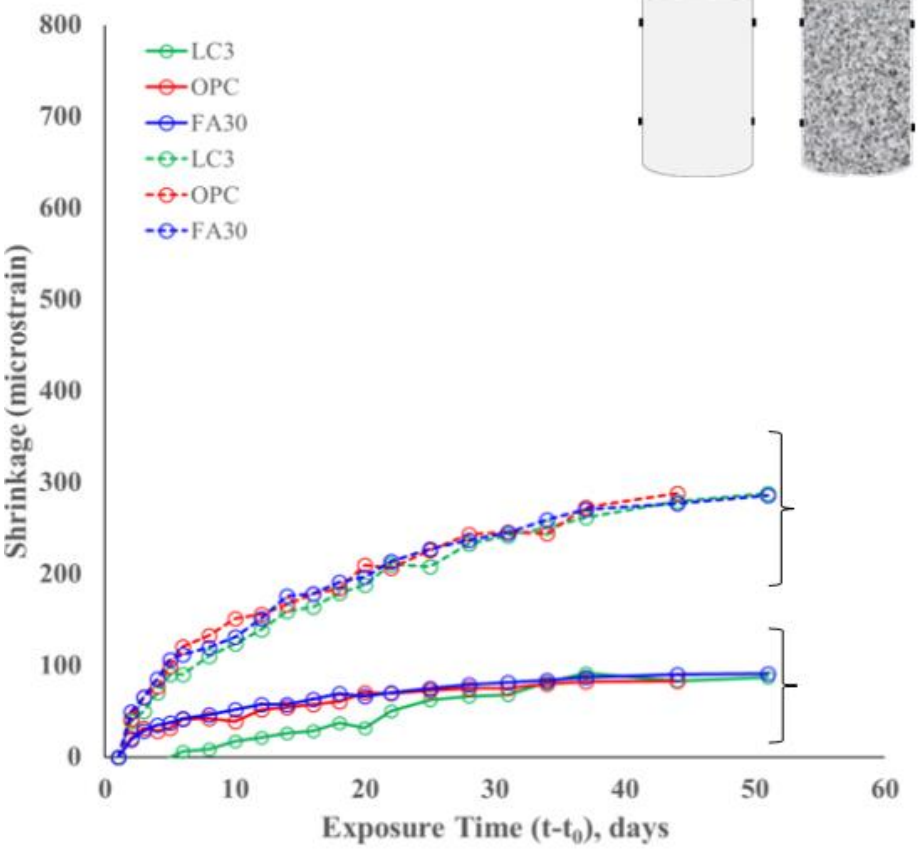
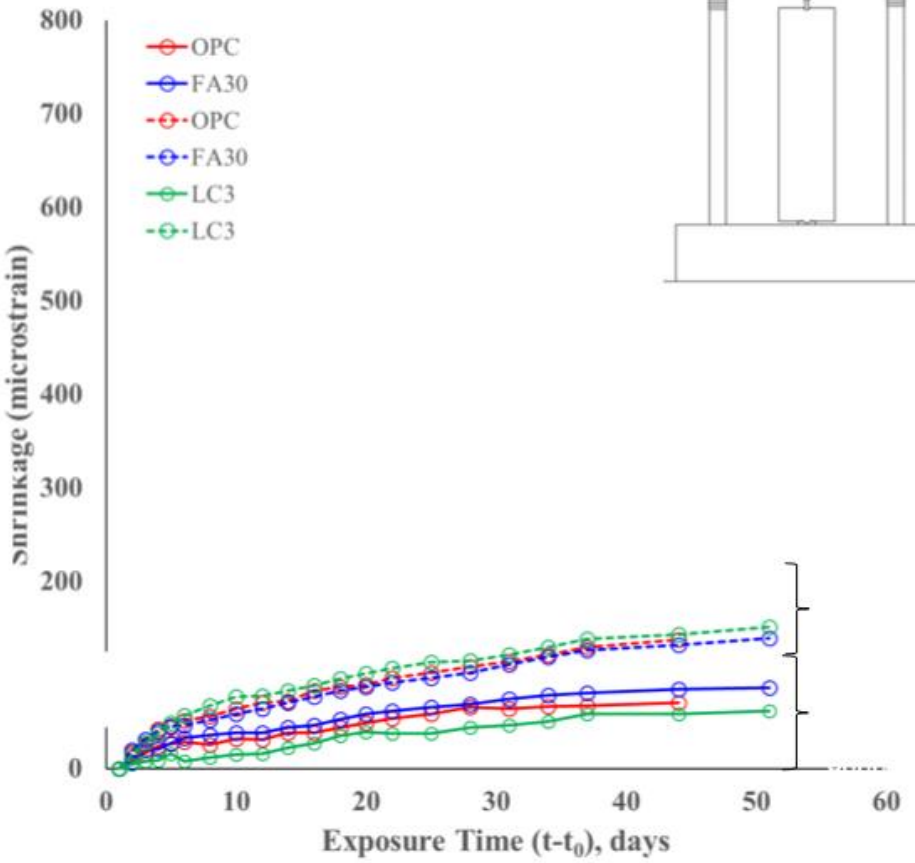
Durability - Chloride Migration Test



Shrinkage: 0.45 w/c, 360 kg cement





Limestone Calcined Clay Cement

Specific conclusions

- Lower alkali-silica reaction
- Higher resistance to chloride ingress, moisture ingress and gas permeation
  - Even at 7 days
- Less need for extended curing
- Fineness and refined pore structure are important

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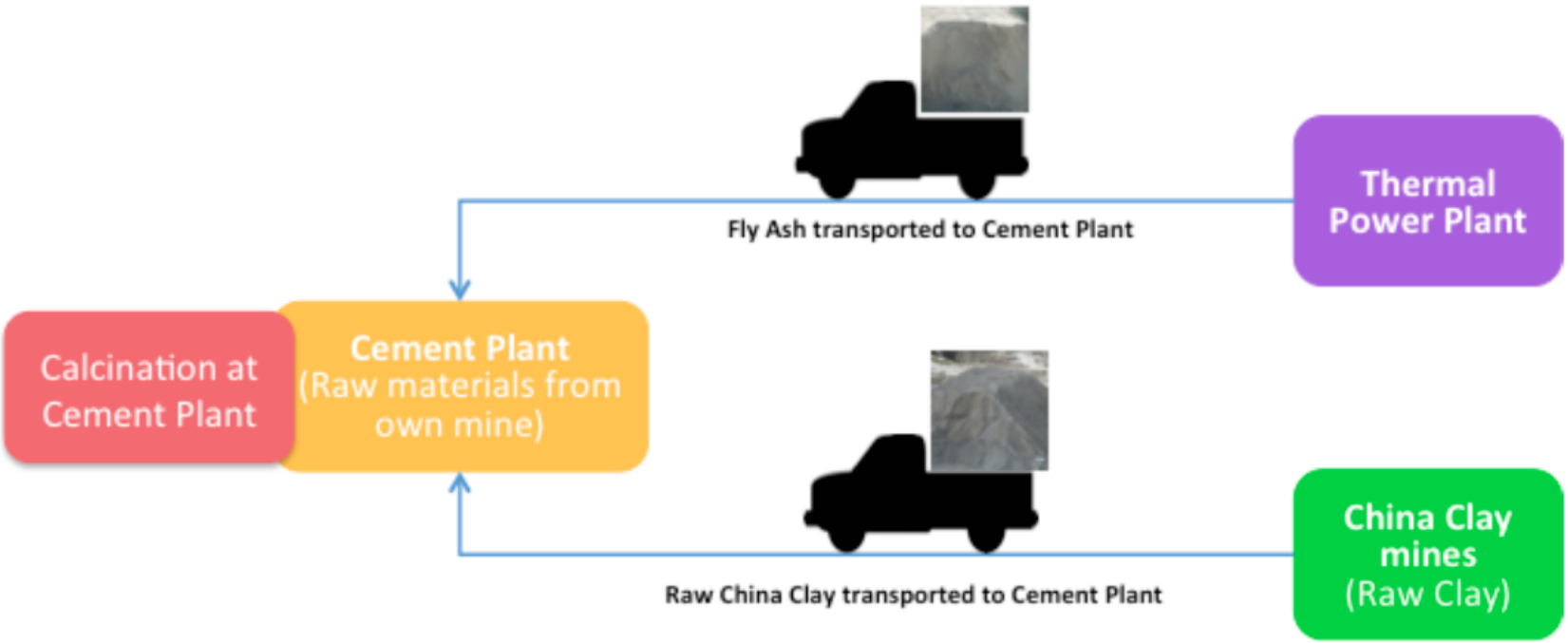
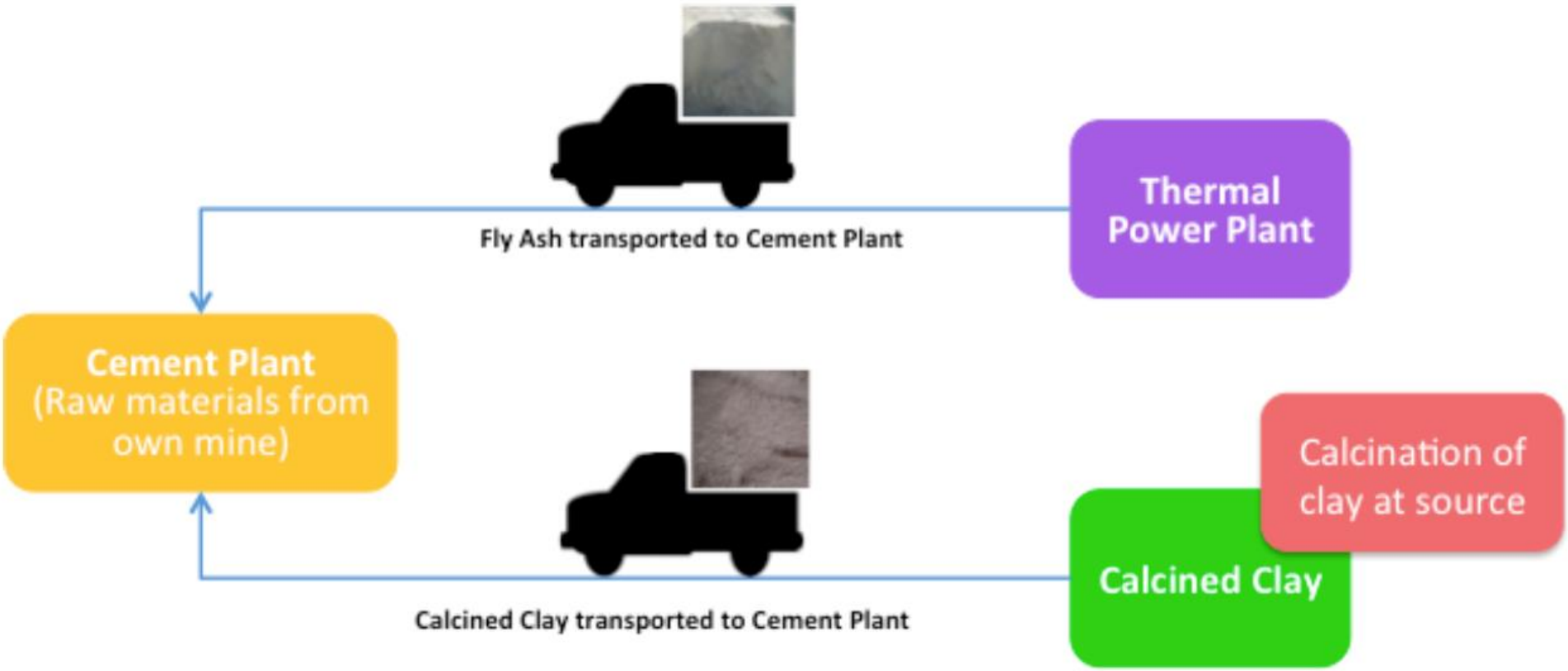
Economy and practice

- Ideal at locations where good quality fly ash is not easily available
- LC^2 as a mineral admixture has potential
  - Allowed in concrete under current standards
  - Gives performance relative to silica fume and metakaolin
- Works due to low clinker content
- Special applications

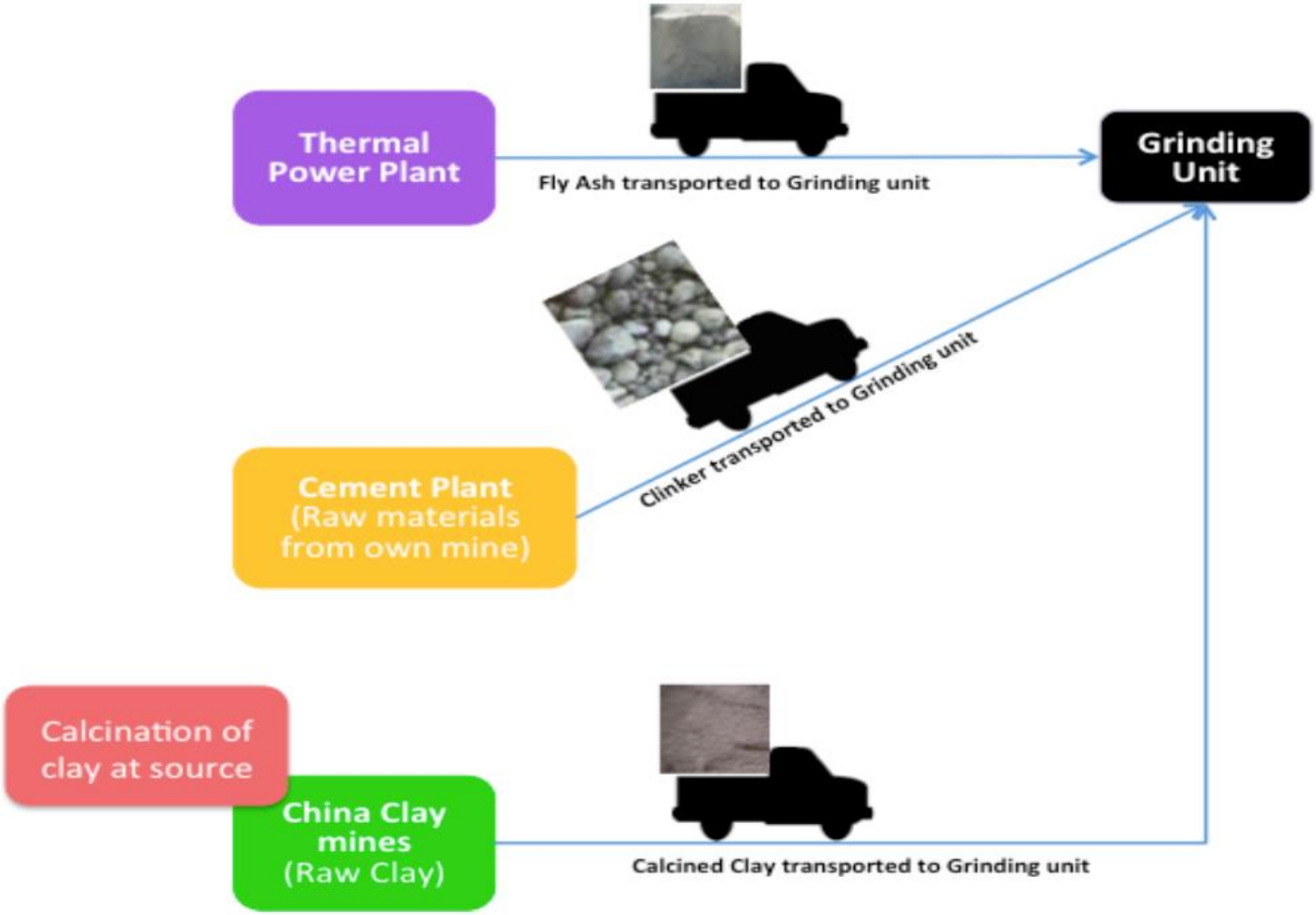
Production scenario 1



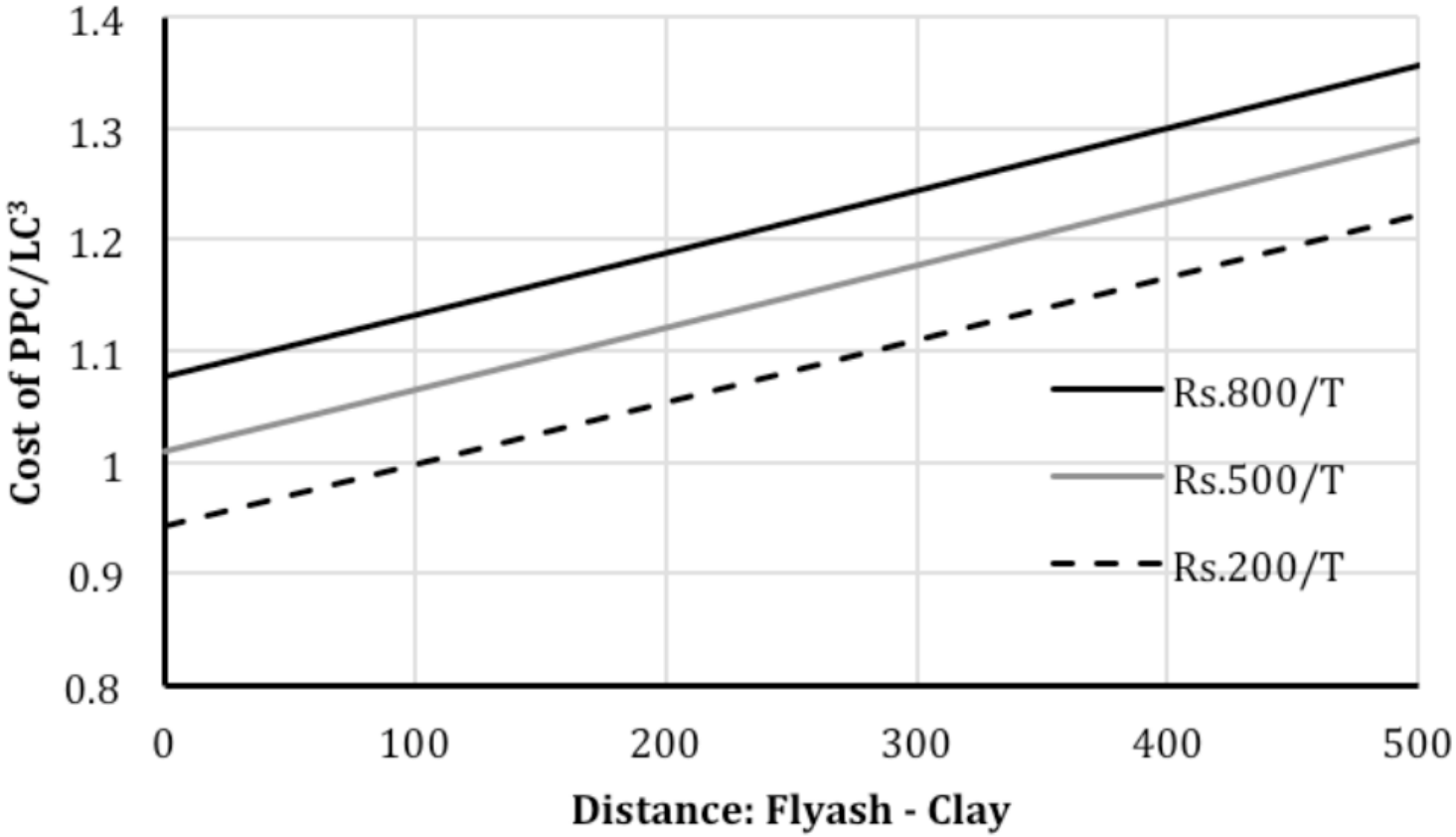
Production scenario 2



Production scenario 3



Analysis of economy



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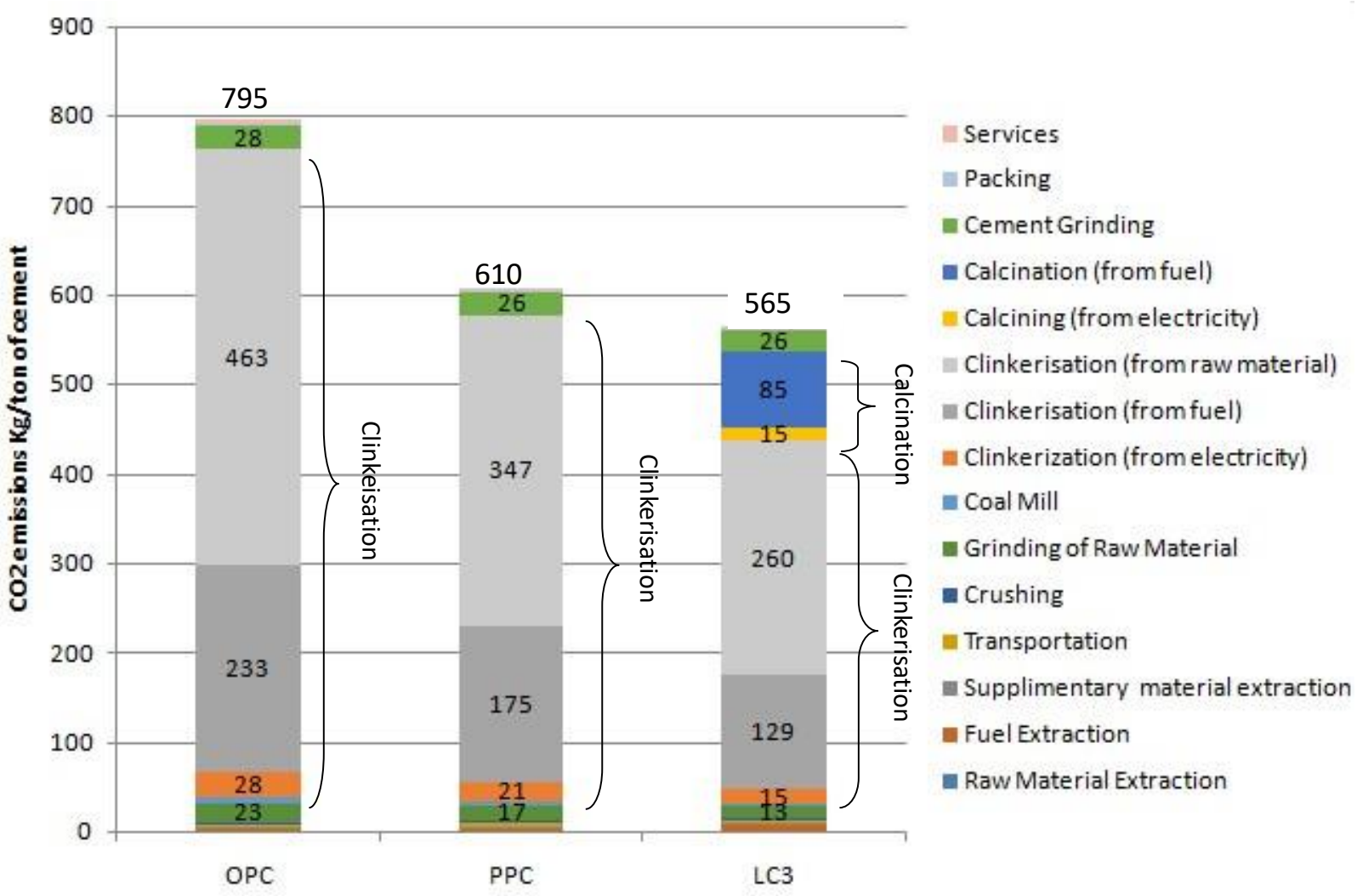
Limestone Calcined Clay Cement LC³

CO_2 emissions (Ground to Gate) for LC^3



Calcined Clay Cement LC3

Field performance

- Data on field performance is being collected
  - Reinforced concrete
  - Unreinforced concrete
  - Building materials
  - Pavements
  - Field test specimens

Calcination

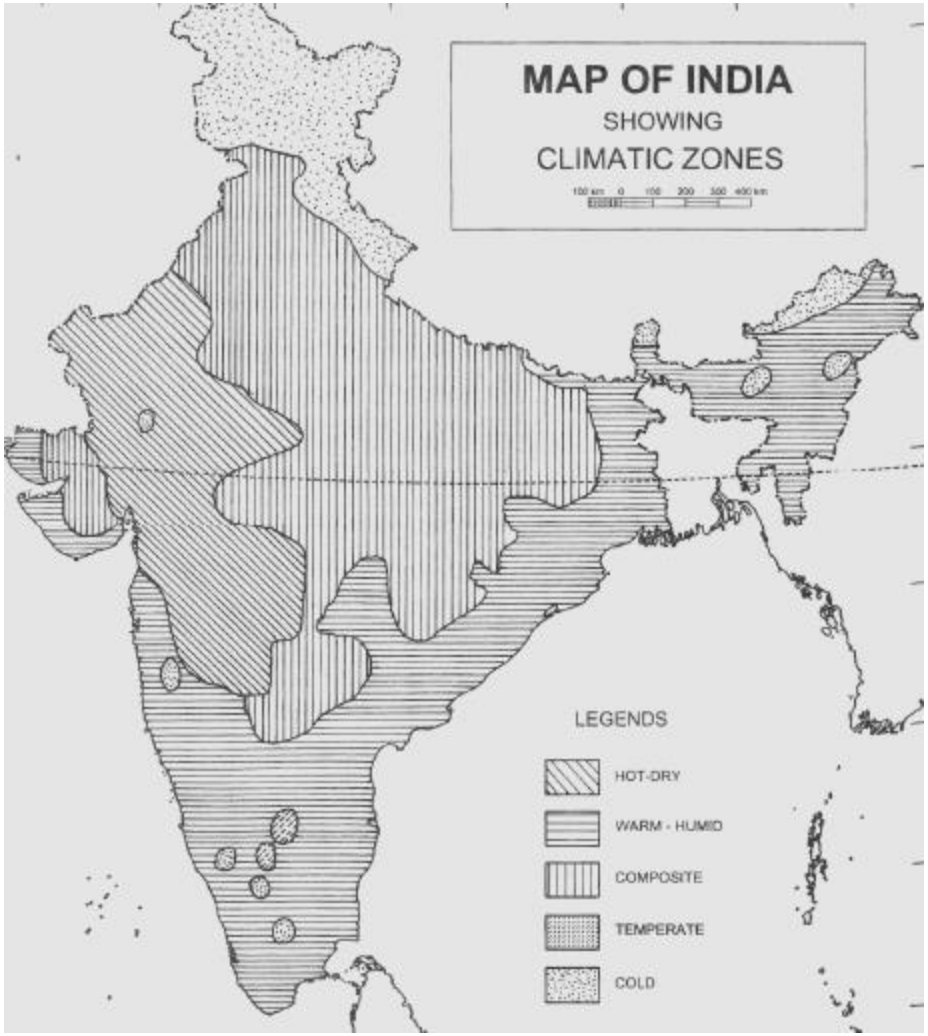
Trial production

Building materials produced

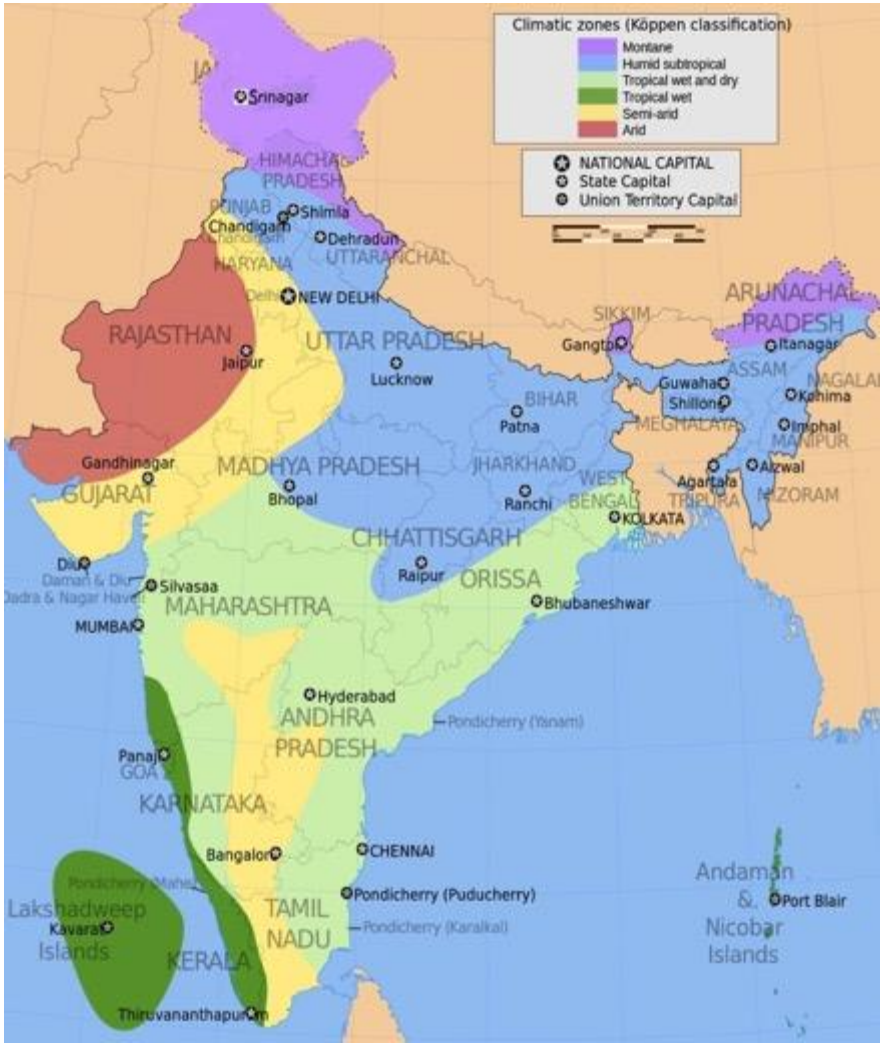
Demonstration structure

Preparation of Specimen : Photos

Indian Climatic Regions



National Building Code of India (NCBI)



Koppen Classification

Column Installation: Photos

AAC Blocks: JK Lakshmi cement

AAC Blocks at temporary building

Industrial production

KJS Concrete Pvt. Ltd., Dadri

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Limestone Calcined Clay Cement LC3

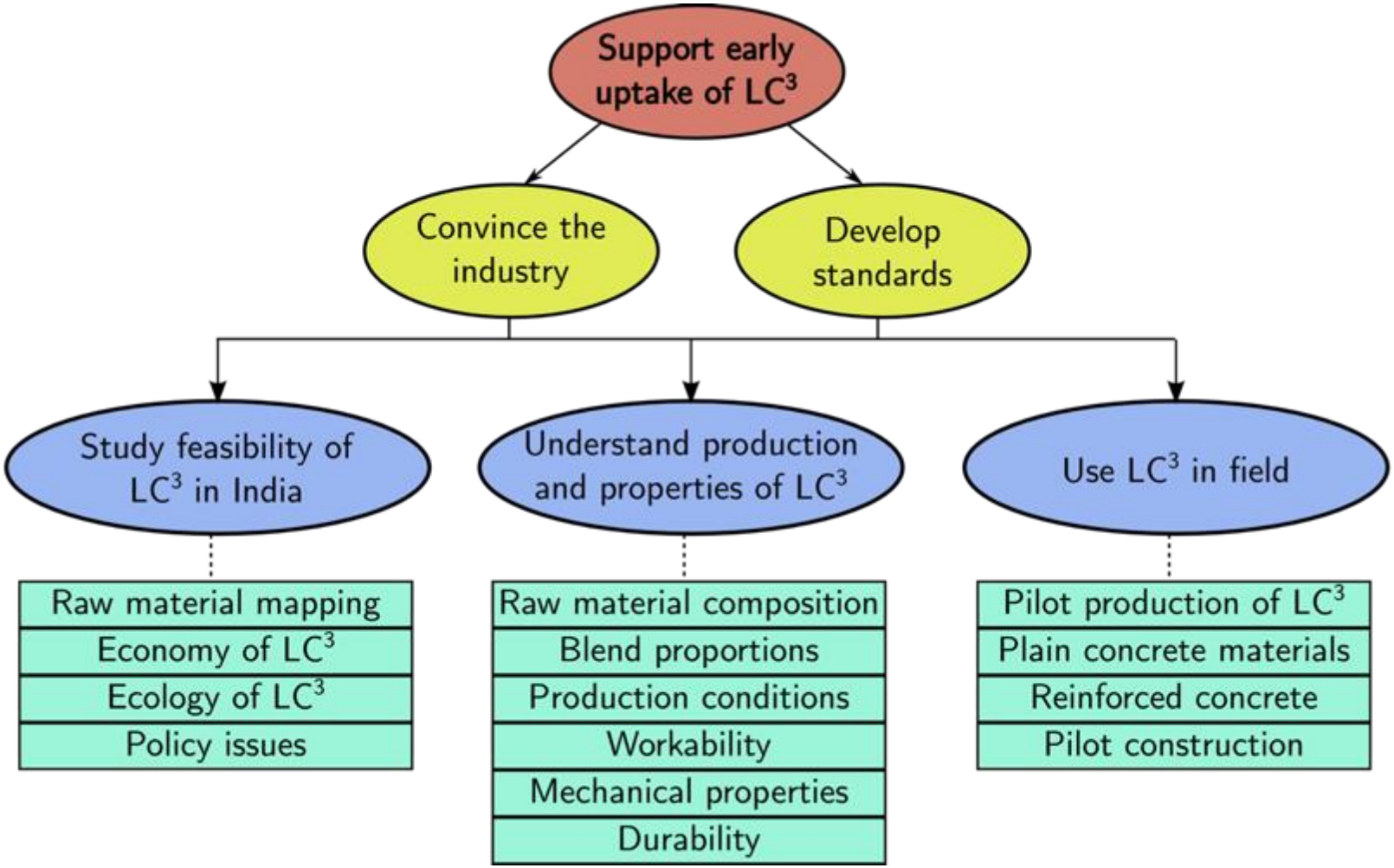
LC^3 testing in external labs

Tests	IIT- Delhi	NCB	JK Lakshmi
Standard Consistency	30%	-	31.25%
Blaine's Fineness (m^2/kg)	>600	>600	>600
Loss on Ignition	6.7%	7.19%	7.44%
Insoluble Residue	-	21.08%	`19.52%
3 Days Strength (MPa)	25.0	29	27.4
7 Days Strength (MPa)	36.9	39	35.8
28 Days Strength (MPa)	46.8	49	49.8

Applications foreseen (LC^2 and LC^3)

- Reduction of clinker content down to 40%
- Reduction of permeability of concrete
- Increase in strength of concrete
- Reduction of cost of concrete
- Improving cohesion of concrete

Towards commercialisation



Towards a standard

- Draft standard being developed by the team
  - A technology note submitted to BIS
  - Complete report from IITs to be submitted to BIS in 2017
  - More work to be done with the industry

Thank you!

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Limestone Calcined Clay Cement LC3