An Exploration of Limestone Calcined Clay Cement (LC^3) as a Low-Carbon Alternative to Ordinary Portland Cement in an Irish Context

Limestone Calcined Clay Cement (LC^3)

A new and developing low-carbon cement, which can reduce CO_2 emissions by up to 40% in comparison to the manufacture of traditional Portland cement

Limestone Calcined Clay Cement

Aims

To explore the application and properties of concrete using LC^3 in an Irish context

Objectives

- *A detailed research into the methods and materials of LC^3 that produce a lower-carbon alternative to Portland cement*
- *An analysis of how various proportions of calcined clay and limestone in LC^3 determine the compressive strength properties of hardened concrete*
- *An assessment of the workability of fresh concrete mixes made with LC^3*
- *An examination of the compressive strength of a selection of LC^3-concrete cubes made with various proportions of calcined clay and limestone*
- *An assessment of the embodied carbon of LC^3 in an Irish context*
- *An exploration of the availability of LC^3 in Ireland*

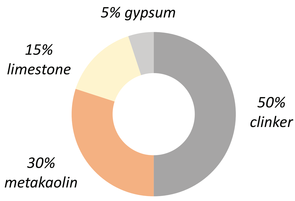
Material Composition

Clinker
The binding agent of cement

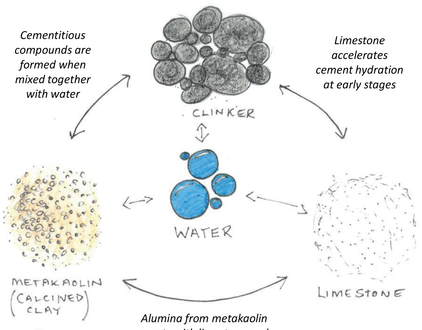
Calcined clay
A pozzolanic material that can reduce clinker content in cement

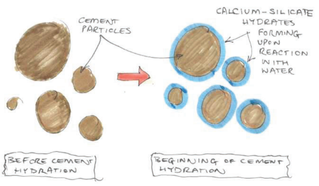
Limestone
A filler in cement that accelerates cement hydration

Gypsum
Regulates the setting time of cement

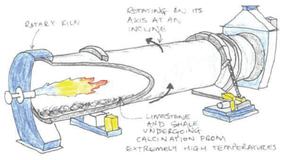


Microchemistry

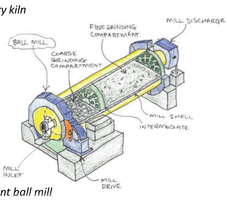




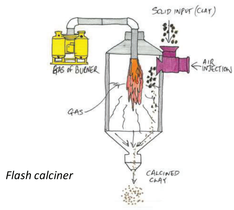
Manufacturing Equipment



Rotary kiln



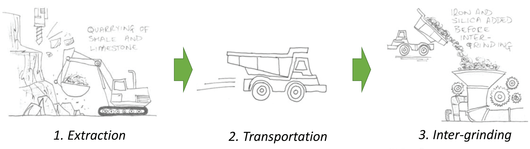
Cement ball mill



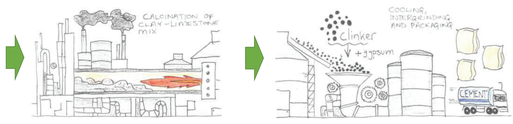
Flash calciner

LC^3 v Portland cement manufacture

Cradle-to-gate process of ordinary Portland cement

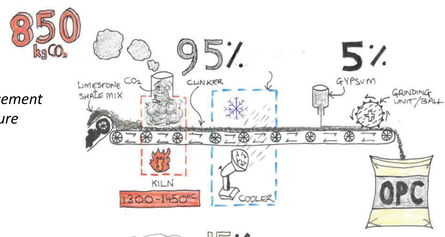


1. Extraction *2. Transportation* *3. Inter-grinding*

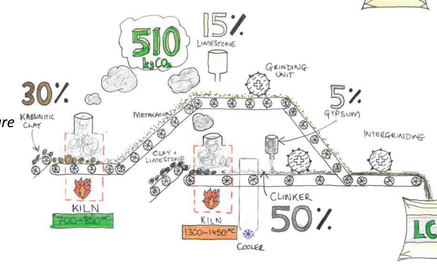


4. Calcination *5. Packaging*

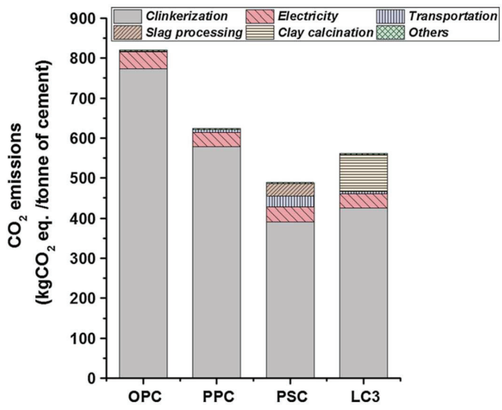
Portland cement manufacture process



LC^3 manufacture process



Environmental Impact



Life-cycle assessments of LC^3 in Cuban and Indian contexts showed a 30% reduction in carbon emissions compared to Portland cement

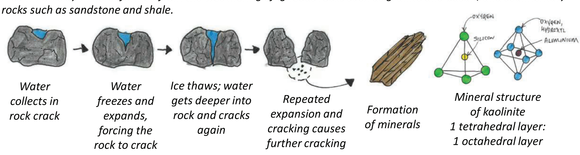
	OPC Manufacture	*LC^3 Manufacture*
Calcination temperatures	*1300-1450°C*	*700-850°C*
Equipment used	*Rotary kiln, ball mill*	*Retrofitted rotary kiln/flash calciner, ball mill*
Electrical energy consumption (per tonne)	*85kWh*	*51.1kWh*
Fuel consumption (per tonne)	*795kWh*	*610kWh*
Total CO_2 emissions (per tonne)	*850kg*	*510kg*

**Figures from FLSmidth*

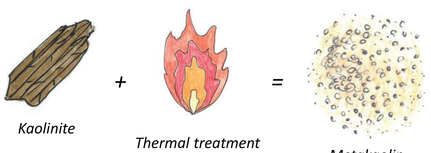
Metakaolin – the key ingredient

Kaolinite

A common clay mineral formed from the weathering of igneous rocks such as granite and basalt, and sedimentary rocks such as sandstone and shale.



Water collects in rock crack *Water freezes and expands, forcing the rock to crack* *Ice thaws; water gets deeper into rock and cracks again* *Repeated expansion and cracking causes further cracking* *Formation of minerals* *Mineral structure of kaolinite 1 tetrahedral layer: 1 octahedral layer*

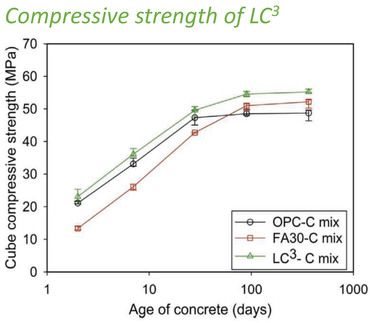


Kaolinite + *Thermal treatment (700-850°C)* = *Metakaolin*

Low-grade clays

Low-grade kaolinitic clays for LC^3 manufacture optimises resource savings and avoids demand from other industries (ceramics, cosmetics, paper)

Compressive strength of LC^3



Greater strength development than Portland cement at all ages

Excellent long-term strength properties

Finer particle size → *Denser microstructure in concrete* → *Increased strength*

The need for LC^3 in Ireland

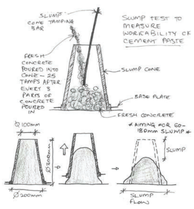
Leading carbon polluters in Ireland in 2022

1. *Dublin Airport - 1,000,000 tonnes of CO_2*
2. *Irish Cement Drogheda plant – 983,000 tonnes of CO_2*
3. *Mannok Cement Cavan plant – 955,000 tonnes of CO_2*
4. *Traffic on Dublin road network – 773,000 tonnes of CO_2*

Methodologies

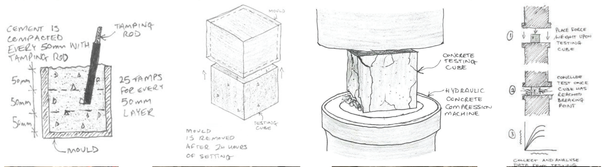
1. An assessment of the workability of fresh concrete made with LC^3

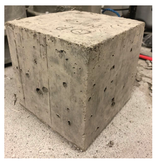
Slump tests of fresh concrete mixes made with LC^3

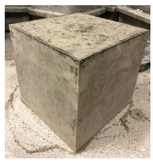


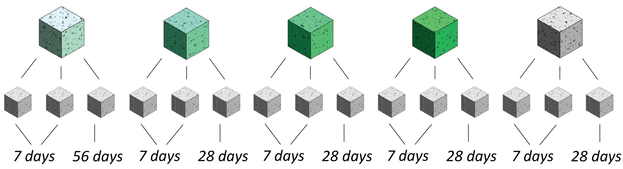
2. An assessment of the compressive strength of hardened concrete made with LC^3

Applying load to a selection of concrete cubes made with LC^3 under a hydraulic compressor









LC^3 Mix 1	LC^3 Mix 2	LC^3 Mix 3	LC^3 Mix 4	OPC mix
50% clinker	50% clinker	50% clinker	50% clinker	100% OPC
25% calcined clay	30% calcined clay	35% calcined clay	40% calcined clay	
20% limestone	15% limestone	10% limestone	5% limestone	
5% gypsum	5% gypsum	5% gypsum	5% gypsum	

Could this mix achieve similar or greater strength as OPC after 56 days?

Mix materials

Portland cement (clinker substitute)

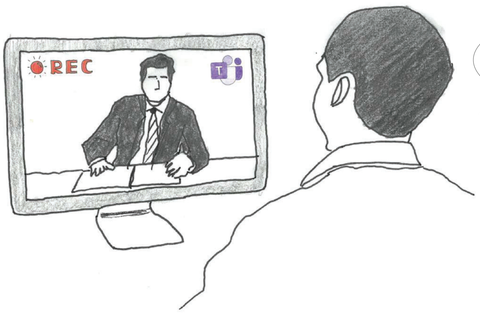
Finish coat plaster (gypsum substitute)

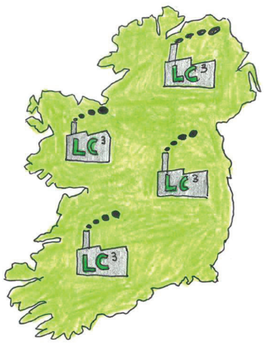
Hydrated limestone powder

High-purity Russian-based Metakaolin

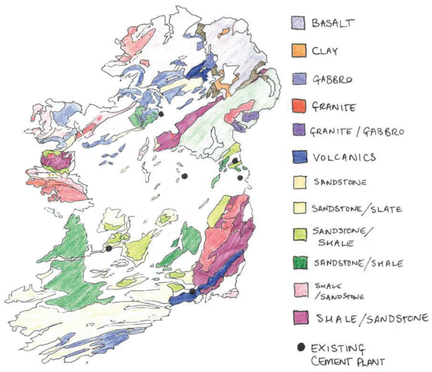
3. An exploration of the availability of LC^3 in Ireland

Semi-structured interviews with cement industry experts





Materials required for LC^3	Available in Ireland
Shale/clay	✓
Metakaolin	×
Limestone	✓
Gypsum	✓



Kaolinite can be found in clays formed from the weathering of igneous and sedimentary rocks such as granite, sandstone, basalt, and shale.

Approximately 54% of Ireland's bedrock is composed of these rocks, which could potentially become extraction sources for calcination.

Sources of LC^3 and MK outside of Ireland

Material	CO_2 per tonne of material
FutureCEM cement, Denmark (LC^3)	625kg*
Argical M 1000, France (MK)	370kg*
Irish Cement Portland cement (CEM I)	912kg

*after shipped to Dublin Port

Participants

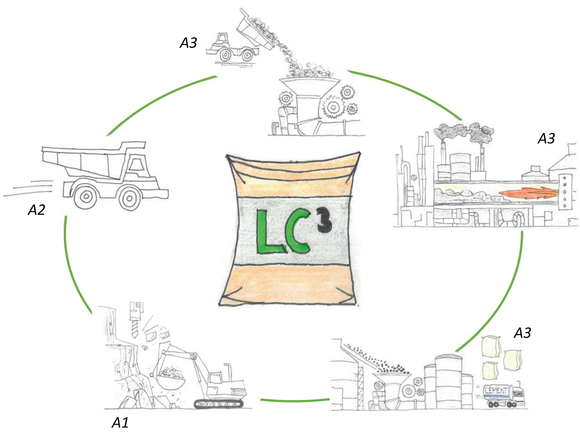
Participant A – Quality and Laboratory manager of a cement manufacturer

Participant B – Committee member of the Institute of Concrete Technology and university faculty member

Participant C – Research and Development manager of a mineral and quarry processor, former Director of Research and Development of a geopolymer and blended cement manufacturer, and committee member of the British Standards Institution

4. An assessment of the embodied carbon of LC^3 in an Irish context

A detailed life-cycle assessment of the manufacture of Derry-based LC^3



Scope of analysis	Value
Scenario of LCA	Fuel and raw materials are extracted and transported to a cement plant based in Antrim to be combusted and processed through grinding, calcination, and cooling units to produce LC^3
System boundaries	A1- A3 (cradle-to-gate)
Declared unit	1,000kg
Sources of fuel and raw materials	≤120km

A1 Extraction

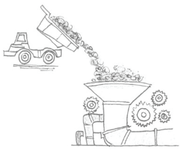
Limestone	975kg
Shale	200kg
Coal	100kg
Kaolinitic clay	345kg
Gyspum	50kg

A2 Transportation

4-axle truck	0.121kgCO_2 per tonne of material per km travelled

A3 Manufacture

Electrical energy consumption for clinker manufacture	110 kWh/tonne of Portland cement
Electrical energy consumption for various processes of metakaolin manufacture	670 kWh/tonne of MK



Calcination of clinker

Quantity of raw materials - 1025kg	0.5323kgCO_2 per tonne of raw material calcined

Processing and calcination of raw materials for MK production

Drying and milling	2.1kWh
Flash calcination	180kWh

Final grinding and packaging of cement

Grinding of MK and limestone	18.81kWh
Grinding of MK-limestone and clinker-gypsum	41.8kWh
Conveying and packing	5.5kWh

Results

1. Workability

Stiff, dry slumps indicate low workability in fresh LC³ concrete

Low workability = extensive and energy-intensive compaction into cube moulds

OPC – fluid, pourable concrete

Cause of low workability → *Insufficient water content*

Resolution → *Superplasticiser admixture*

- *Increases concrete strength*
- *Improves workability*
- *Reduces porosity and water demand*

Dry, stiff, and solid slump

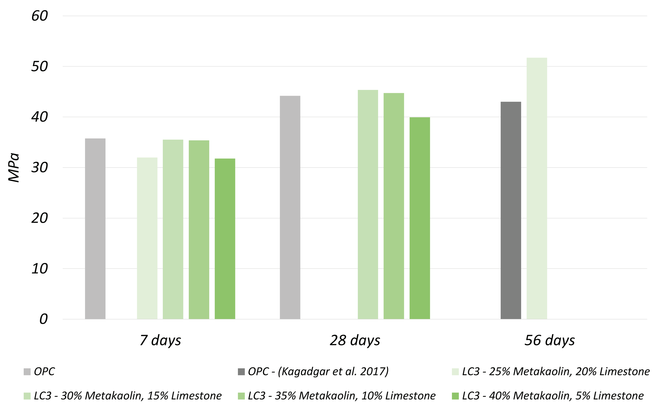
+

Superplasticiser (1.2% of cement content)

=

Fluid, workable concrete

2. Compressive strength



30% MK-15% Limestone and 35% MK-10% Limestone → *Similar strength development to OPC at 7 days; Greater strength development than OPC at 28 days*

25% MK-20% Limestone and 40% MK-5% Limestone → *Suboptimal for maximising strength development at 7 and 28 days*

25% MK-20% Limestone → *Impressive long-term development in regards to OPC*

2. Availability of LC³ in Ireland

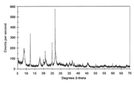
Banah UK

banah UK Ltd
SUSTAINABLE BUILDING PRODUCTS

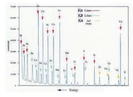
- *Derry-based manufacturer of geopolymer and blended cements; utilised metakaolin in their products – established in 2008*
- *Extracted readily available precursor/kaolinitic clays from Antrim, Northern Ireland*
- *Banah's operations have been inactive since 2019*

Depositories of kaolinitic clays in Ireland

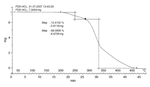
According to interview participants, cement manufacturers in Ireland are currently surveying potential depositories of kaolinitic clays for quarrying



X-ray fluorescence (XRF); analysis of the elemental composition of clay

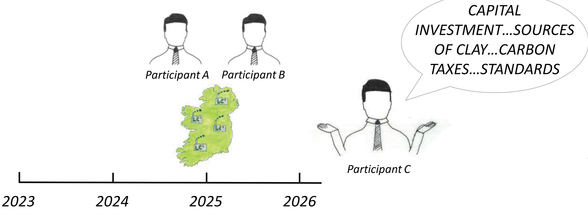


X-ray diffraction (XRD); analysis of the crystallographic structure



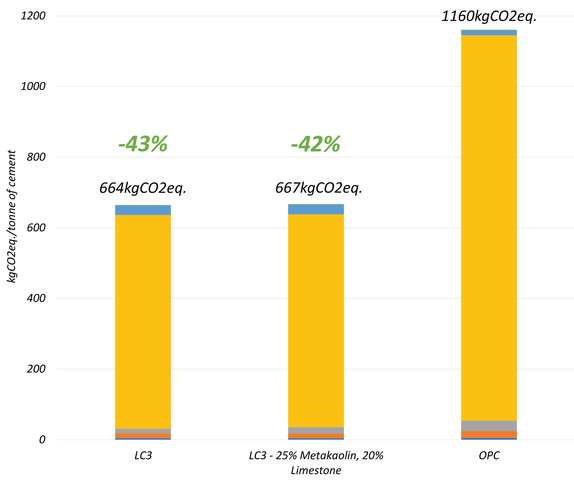
Thermogravimetric analysis (TGA); analysis of the thermal stability of clay

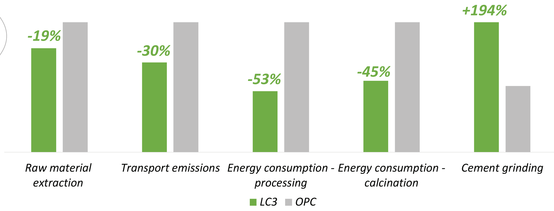
Estimated time of LC³ production in Ireland



3. Embodied carbon of Antrim-based LC³

LCA Results





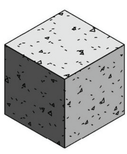
LC³ in a greater context

Optimised resource efficiency

An LC³-50 mix comprising 25% metakaolin-20% limestone promotes increased resource efficiency

Less kaolinitic clay is extracted, therefore, increased conservation of this valuable material is achieved

Carbon emissions associated with various cements for concrete production



Concrete made with OPC (1m³)
Cement content – 435kg

396.72kgCO_2 emitted

Concrete made with LC³ + superplasticiser admixture (1m³)
Cement content – 435kg
Superplasticiser content – 5.22kg

257.52kgCO_2 emitted

Cement emissions in Ireland

Irish Cement are the largest cement manufacturer in Ireland, producing approximately 3.5 million tonnes of cement and 2.75Mt of CO^2 per annum

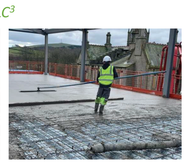
Manufacturing their own LC³ product will reduce their emissions substantially

Irish Cement A CRH COMPANY → Irish Cement A CRH COMPANY LC³

2.75Mt of CO^2 (2022) → *1.6Mt tonnes of CO^2*

Potential applications of LC³

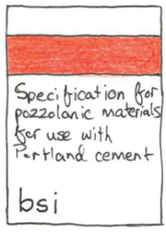
Domestic internal floors C25/30

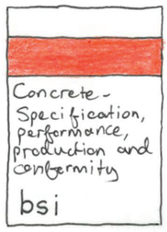


Commercial internal floors and external slabs and yards C28/35

Dry and stiff mixes of fresh LC³ concrete are ideal for roller compacted concrete applications e.g. road pavements

Blended cement and concrete mix design standards





- *Minimum cement content*
- *Maximum water/cement ratio*
- *Maximum replacement of CEM I with specific SCMs*

BS 8615-2 to be revised in the near future to facilitate the use of metakaolin in blended cements, according to Participant C

BS EN 206 currently does not recognize LC³ within potential constituents in concrete mixes

A shift towards a performance-based standard for blended cement concrete mixes such as LC³ is necessary to decarbonise the cement industry