Alternative Binders for Concrete Other Than Cement

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What is Concrete?

- Cement + Aggregates + Water ???
- Binders + Aggregates + Water
- Inorganic Binders (eg. Cement, Lime, Gypsum)
- Organic Binders (epoxy resin, acrylic emulsion)
- Supplementary Binders (PFA, GGBS)

What did the builders use before cement was invented?

Can Concrete have no cement?

Important Milestone in the History of Concrete Binders

- ~ 3000 BC
- The Egyptians began to use mud mixed with$_{s}$ traw to bind dried bricks. They also used gypsum mortars and mortars of lime in the building of the pyramids.
- The Chinese used cementitious materials in the construction of the Great Wall.

Important Milestone in the History of Concrete Binders

- ~ 800 BC

  The Greeks used lime mortars that were much harder than later Roman mortars.

- ~ 300 BC

  The Babylonians and Assyrians used bitumen to bind stones and bricks together.

Important Milestone in the History of Concrete Binders

- ~ 299 BC to 476 AD
- The Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius to build many famous Roman structures. They used broken bricks and stone aggregates embedded in a mixture of lime putty with brick dust or volcanic ash by the Romans.

Important Milestone in the History of Concrete Binders

- 1774
- John Smeaton discovered that combining quicklime with other materials created an extremely hard material that could be used to bind together other materials.

Important Milestone in the History of Concrete Binders

- 1793
- John Smeaton found that the calcination of limestone containing clay produced a lime that hardened under water (hydraulic lime).

Important Milestone in the History of Concrete Binders

- **1796**
  - **An Englishman, James Parker, patented a natural hydraulic cement by calcining nodules of impure limestone containing clay, called Parker's Cement or Roman Cement.**

Cement: A Heavy CO_2 Emitter

- Common estimation on the CO_2 emission from cement production: 0.6 – 1 T of CO_2 per 1 T of cement production.
- In China, the statistics in 2005 for the CO_2 emission from cement production:

0.815 T of CO_2 per 1 T of cement production

0.39 T of CO_2 is from the burning of fossil fuel (coal) and 0.415 T is from the decomposition of raw material

$$(CaCO_3 \xrightarrow{\text{Heat}} CaO + CO_2)$$

$$(MgCO_3 \xrightarrow{\text{Heat}} MgO + CO_2)$$

(Heating Temperature for clinker: ~ 1450 ℃)

Alternative Binders for Concrete other than Cement

- **Lime Concrete:**
  - Using Lime: $Ca(OH)_2$ as binder
  - Also produced from $CaCO_3$

    $CaCO_3 \xrightarrow{Heat} CaO + CO_2$

    $CaO + H_2O \longrightarrow Ca(OH)_2$

    (Heating Temperature: ~ 1000 - 1100 ℃
  - Estimated CO_2 emission per T of lime production:

    ~ 80％ of cement.
  - After hydration, $Ca(OH)_2$ in lime concrete takes back CO_2 from the air and turns back to hardened $CaCO_3$

    $Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$

Lime Vs Cement in CO2 emission

- CO_2 emission from burning of fuel: Lime = ~80% of that of Cement
- CO_2 emission from power consumption for production process (e.g. grinding): Similar for Lime & Cement
- CO_2 is also produced during chemical process of $CaCO_3$ to CaO but same amount of CO_2 will be taken up again during hydration and carbonation process (very long process)

Alternative Binders for Concrete other than Cement

- Gypsum Concrete:
- Concrete using Gypsum as the main binder
- Naturally mined gypsum is in the form of ($CaSO_4 \cdot 2H_2O$) (calcium sulfate dihydrate)
- Raw gypsum ores are processed to form a variety of products suiting for different purposes (portland cement additives, soil conditioners, rheology modifying additives, etc.)
- When used as a binder in concrete, the most common form is ($CaSO_4 \cdot {}^1/_2H_2O$) (Calcium sulfate hemihydrate)

Gypsum Vs Cement in CO_2 emission

- **Production process of Calcium Sulfate Hemihydrate (Gypsum binder):**

Calcium Sulfate Dihydrate → crushed → dried → ground → Calcined at 120 - 150℃ → Calcium Sulfate Hemihydrate

Gypsum Vs Cement in CO_2 emission

- CO_2 emission from energy consumption for calcination: 120 – 150°C Vs 1450°C (10 % of cement)
- CO_2 emission from electricity consumption for grinding process (similar)
- CO_2 emission due to chemical reaction: none for gypsum

Strength Performance of Concrete Using Lime as Binder

OPC (kg/m^3)	Lime (kg/m^3)	PFA (kg/m^3)	Total binder (kg/m^3)	Slump (mm)	W/B Ratio	7-day (MPa)	28-day (MPa)	56-day (MPa)
300			300	95	0.60	25.5	32.5	34.5
150	150		300	95	0.50	17.0	25.0	27.5
164	164		328	110	0.46	18.0	26.0	29
178	178		356	120	0.42	21.0	28.0	31.5
119	119	119	357	120	0.42	14.0	20.5	27.5
	89	267	356	120	0.42	2.5	4.5	6.0
	267	89	356	90	0.42	2.5	4.0	5.5

Strength Performance of Concrete Using Gypsum as Binder

OPC (kg/m^3)	Gypsum (kg/m^3)	PFA (kg/m^3)	Total binder (kg/m^3)	Slump (mm)	W/B Ratio	7-day (MPa)	28-day (MPa)	56-day (MPa)
300			300	95	0.60	25.5	32.5	34.5
100	200		300	95	0.63	11.5	15.5	16.5
150	150		300	100	0.57	15.0	21.0	23.5
100	100	100	300	110	0.57	8.5	15.0	21.5
164	164		328	100	0.52	14.0	19.5	22.0
109	109	109	327	110	0.52	7.0	13.5	19.5
178	178		356	100	0.48	17.0	22.5	24.0
119	119	119	357	100	0.48	10.5	16.0	23.0

Strength Performance of Concrete Using Both Lime & Gypsum as Binder

OPC (kg/m^3)	Lime (kg/m^3)	Gyp-Sum (kg/m^3)	PFA (kg/m^3)	Total Binder (kg/m^3)	Slump (mm)	W/B Ratio	7-day (MPa)	28-Day (MPa)	56-Day (MPa)
100	83	84	89	356	100	0.51	8.0	14.5	21.5
100	73	73	82	328	110	0.55	7.5	13.0	19.0
100	62	63	75	300	90	0.63	6.0	12.5	17.0

Findings from Test Results Using Lime as Binder in Concrete

- **Less water requirement to attain the same workability than that of plain OPC mix**
- **Lime also provides the required alkaline environment ($Ca(OH)_2$) to activate the pozzolanic properties of PFA in strength development**
- **When works with OPC in the same mix, the stiffening time (visual check) is only slightly prolonged (similar to PFA)**

Findings from Test Results Using Lime as Binder in Concrete

- **Works well with ordinary water reducing retarding admixtures for OPC mixes**
- **Hydration process takes much longer time than OPC mixes ($Ca(OH)_2$ takes up CO_2 to form $CaCO_3$)**
- **Attain reasonable compressive strength at 28-day and 56-day (still gains strength after 56-day)**
- **Works with PFA even with a small quantity of lime (much longer stiffening time)**

Findings from Test Results Using Gypsum as Binder in Concrete

- **Ordinary water reducing agent for OPC mixes still works with Gypsum but special retarder is required to maintain adequate workable time**
- **More water is required than lime concrete for achieving similar workability**
- **When targeting at similar workability, the W/B ratio is higher for Gypsum Concrete than Lime concrete**
- **No early strength was tested but it could be noticed that the demoulding time for Gypsum Concrete was shorter than Lime Concrete**

Findings from Test Results Using Gypsum as Binder in Concrete

- **Gypsum is close to neutral itself and therefore does not provide an alkaline environment for the pozzolanic reaction of PFA. Therefore, it does not work well with PFA alone.**
- **A triple blend binder design (OPC-Gypsum-PFA) has a lower 7-day strength than a OPC-Gypsum mix design but the 28-day strengths of both designs are similar**
- **In theory, gypsum is much more stable than OPC in volume change and is therefore expected to have a lower drying shrinkage value (not tested this time) for a similar W/B ratio**

Reduction of Green House Gas by Using less Cement

- Cement is a very non-environmental friendly material
- To reduce the production of green house gas (CO_2), people should attempt to use less cement in concrete
- Do not use excessive cement in concrete mix design (A lower W/B ratio is more effective than a high cementitious content for durability)
- Use alternative binders (lime, gypsum)
- Use supplementary binders (PFA, GGBS)

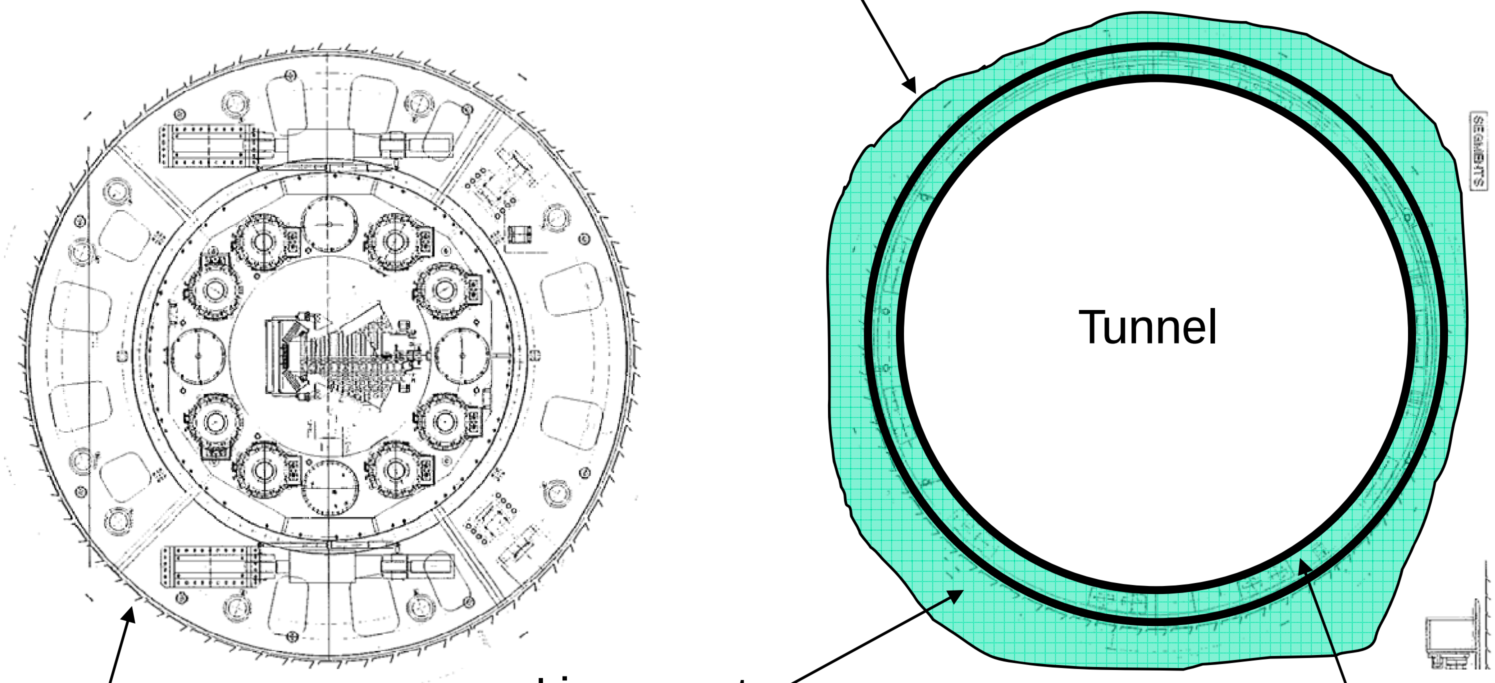
Application of Lime & Gypsum to Replace Cement in Part or in Whole

- Non structural elements when used as the sole binder in concrete
- Co-binders in concrete for light duty structural elements
- Co-binders in concrete to modify the properties of the resulted concrete (rheology modifier: e.g. reduce drying shrinkage, stiffening time, etc.)
- Grouting material for the gap surrounding tunnel lining
- Grouting material for abandoned underground pipelines or similar applications

Application of Lime & Gypsum to Replace Cement in Part or in Whole

- Floor screed
- Repair concrete/mortar (normal set, fast set, instant set)
- Plasters & Renders (for outdoor use, better to have cement)
- Skim coats, tile adhesives
- Texture Cement Paint
- Many others applications

A Recent Project in HK using Lime/PFA Mortar to fill up gaps between Segment Lining & Excavated Circumference by TBM



Recommendation for further studies

- Properties (drying shrinkage, water absorption, durability, etc.) other than compressive strength for concrete using alternative binders
- Application of alternative binders in concrete for minor usages.
- Exploring and allowing more use of alternative binders in concrete

Don’t say cement only when talk about concrete!

- Thank you very much!
  - Hong Kong Concrete Institute
    - www.hongkongci.org