Cementing a Greener Future: A Comparative Analysis of Cement Sustainability and Performance

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Background

Concrete is globally favored for its affordability, accessibility, and user-friendliness in construction. Yet, its widespread use comes with environmental consequences. The cement industry is responsible for approximately 8% of global CO2 emissions, trailing only fossil fuel combustion. The production process, particularly the calcination of clinker, is highly energy-intensive and emits significant carbon. Consequently, there is a growing shift in cement production towards more sustainable methods.

Objective

This research aims to investigate alternative cementitious materials with reduced clinker content while maintaining concrete performance standards.

- Evaluate environmental impacts of three cement types using EPD sheets.
- Review Real-World Examples by examining commercial use cases of alternative cement mixes.
- Evaluate Early-Age Strength through experimentation: Measure early-age strength of concrete samples.
- Objective: Substitute Ordinary Portland Cement (OPC) with Limestone Portland Cement (LPC) and Supplementary Cementitious Materials (SCMs) without compromising performance.
- Evaluate effect of LPC and SCM substitutions on early-strength gain and properties of fresh concrete.

Environmental Product Declaration

Environmental effects vary among different cement types, as illustrated in the following table. Table below shows the environmental impact based on EPD's cradle-to-gate life cycle.

Production per 1 metric ton of cement	Global Warming Potential, GWP (kg CO2 eq)	Ozone depletion potential, ODP (kg CFC-11 eq)	Acidification Potential, AP (kg SO2 eq)	Smog formation potential, SFP (kg O3 eq)
OPC	922	2.10×10^{-5}	1.75	32.9
LPC	846	2.17×10^{-5}	1.64	30.2
OPC + 30-40% SCM	405	1.04×10^{-5}	1.27	27.2

Literature Review

The Portland Cement Association and Cement Association of Canada found that LPC had no significant performance difference from OPC. The compressive strength of PLC was improved when incorporating fly ash and slag, both of which are supplementary cementitious materials (SCMs).

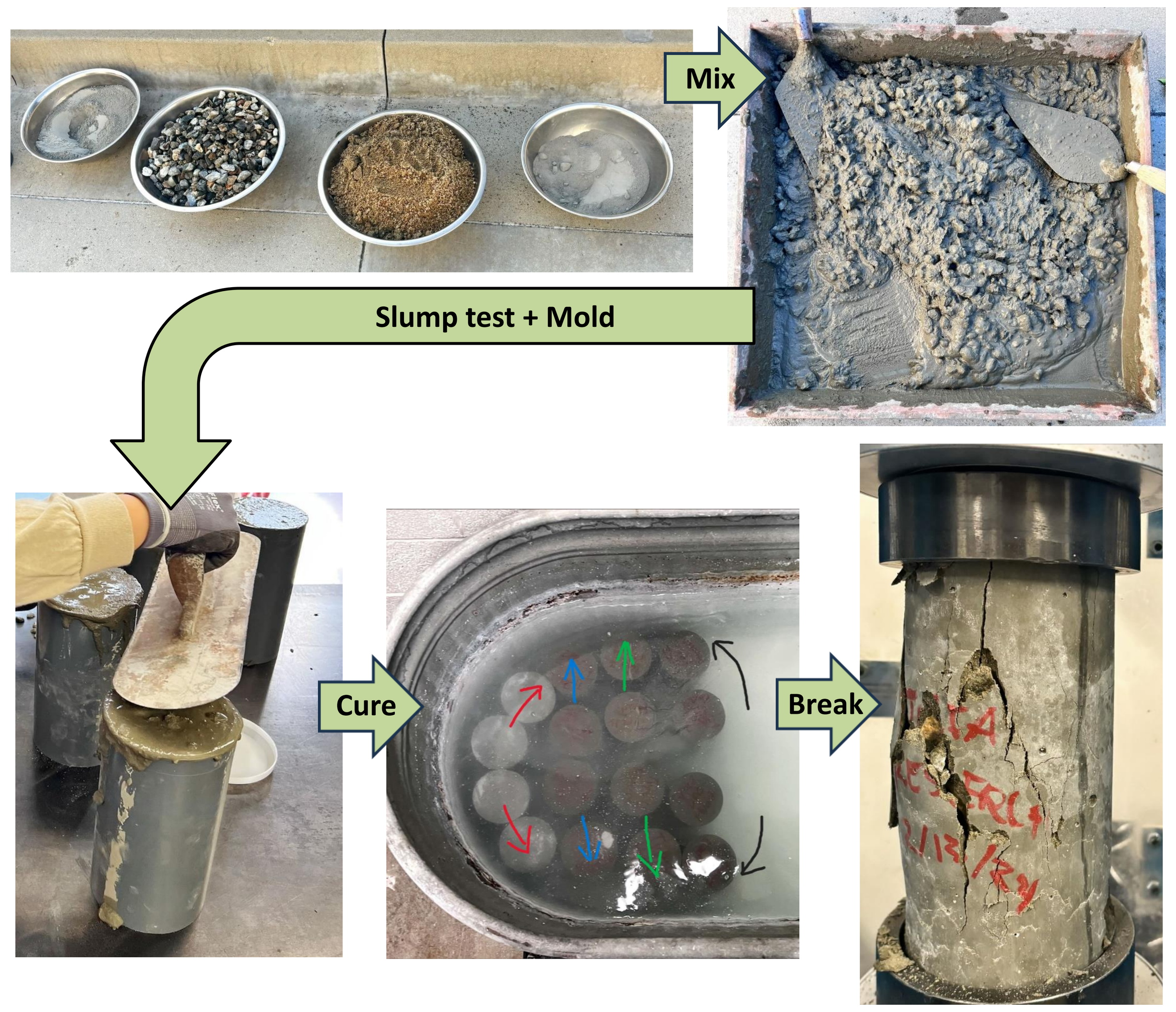
Type 1L PLC and SCMs are already used in real-life projects such as:

- Davis Wide Stadium Expansion & Renovation, TX
- Beverly One Condominiums in Beverly Hills, CA

Data collected from Cement Association of Canada shows that the addition of fly ash causes slower early-strength gain. Slump was higher with the addition of fly ash in the concrete mix, increasing workability.

Experimental Factorial

- Types of cement (2):
  - Type II OPC
  - Type 1L LPC
- SCMs (2):
  - No SCM
  - 35% fly ash
- Replicates: 4 cylinders (4x8), 16 cylinders total.
- Measure: slump and compressive strength after 7 and 14 days.
- Mix design (by weight): 0.55 parts water, 1 part cementitious materials, 2 parts fine aggregate, and 2.5 parts coarse aggregate.



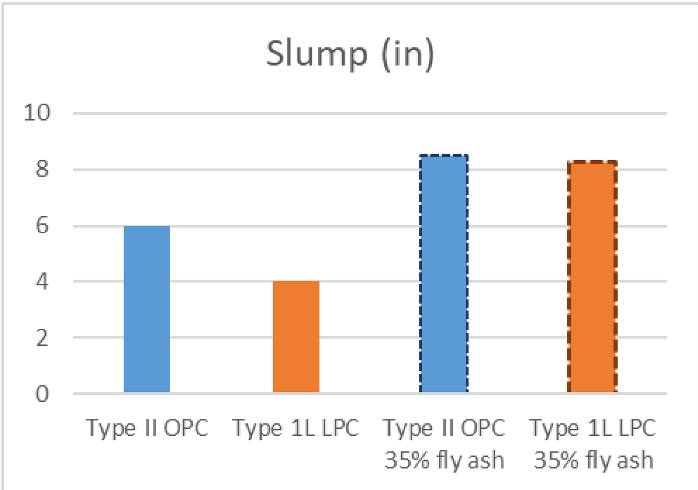
From left to right, top to bottom, the steps of batching concrete cylinders. 4" by 8" molds were used. After pouring into the molds, the concrete is broken with a compressive testing machine after 7 and 14 days.

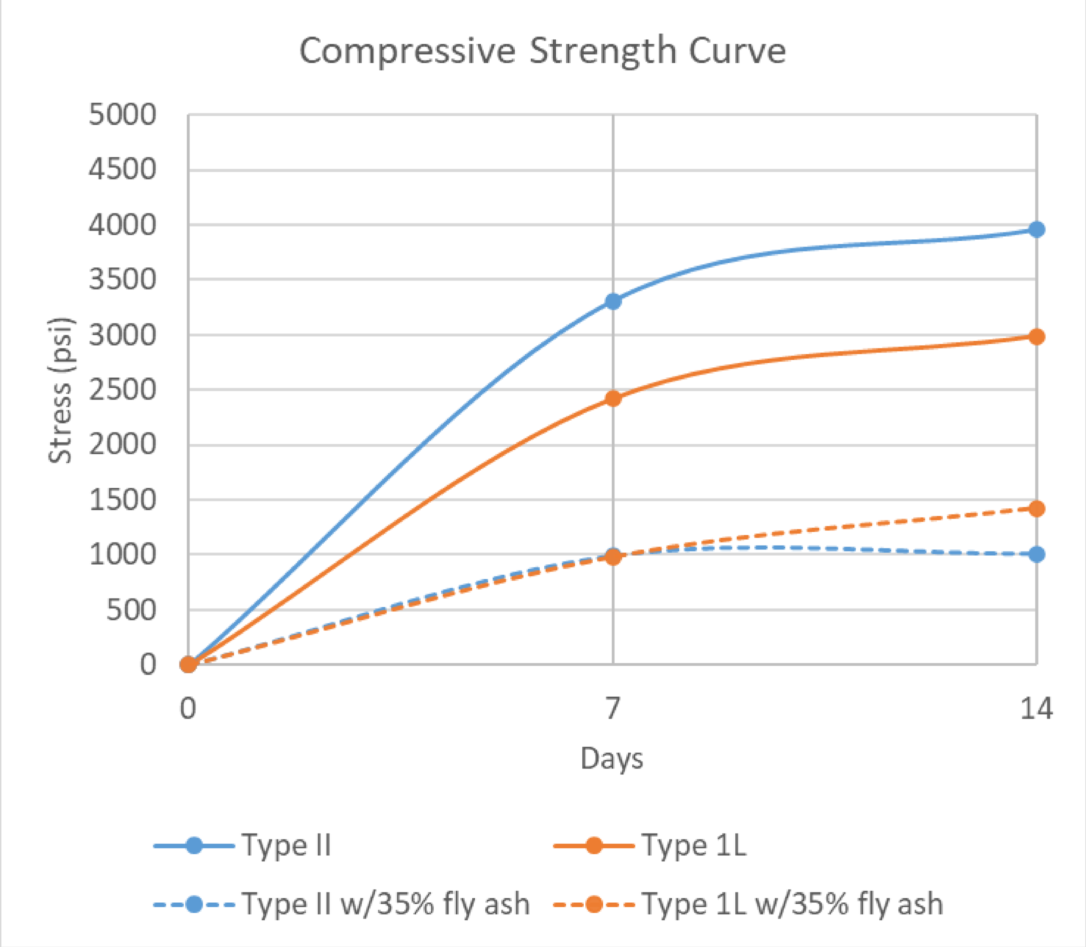
Results

- The cylinders containing fly ash had lower early-strength gain compared to those with no fly ash.
- OPC with no SCMs had the highest early-strength gain out of all the samples.
- LPC reduced the workability of the concrete compared to that of OPC, indicated by the reduced slump in concrete specimens containing it.

Substitution of fly ash for OPC by 35% weight increased workability significantly.

Chart on the right shows the slump of four different types of concrete mixes. The higher the slump, the more workable the mix is.





Cement Type	Environmental Effects	Performance Effects
Portland Cement	High environmental impact	High compressive strength
Fly Ash	Notable environmental impact	More workability, reduced early-strength gain
Limestone Cement	Reduced environmental impact	Less workability, good compressive strength
Slag	Lower environmental impact	N/A

Conclusion

- Cement Types Impact Early-Gain Strength: Despite the lower environmental impact, fly ash reduced the 7- and 14-day compressive strength significantly.
- Fly Ash Influence on Minimum Strength: Specimens with fly ash fail to reach minimum strength at 28 days, possibly due to a relatively high water-cement ratio.
- Performance Comparison: Type 1L cement seems to have lower early strength when used in the same amount as Type II OPC.
- Fly ash specimens do not seem likely to achieve the same strength as the specimens without flyash
- Limestone Cement and Fly Ash: Aims to enhance long-term strength beyond 28 days, according to studies monitoring strength up to 90 days.

Future Research

Future research will be required to truly understand all the SCMs have for potentially replacing cement for the environment. Specimens containing varying amounts of both fly ash and slag should be tested at 28 days and later to further explore how these findings seem to contradict conventional wisdom.

Literature Cited

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Cement Association of Canada

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