Low-Portland Cement Concrete Mixtures Made with Ultrafine Granulated Blast Furnace Slag and Medium-Grade Metakaolin

Presenter: Saeid Ghasemalizadeh, PhD candidate, University of Calgary

Rahil Khoshnazar, PhD, PEng, Associate Professor, University of Calgary

Vaidehi Pitre, PhD, Postdoctoral Fellow, University of Calgary

Introduction

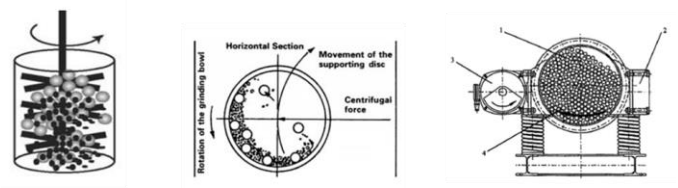
- Replacing Portland cement with SCMs in concrete
  - Reducing the GHG emissions
  - Improving late-age strength and durability

- Increasing the replacement level of cement with SCMs in concrete
  - Reduction in the compressive strength of concretes

Dilution effect of PC replacement	Lower reactivity of SCMs compared to PC

Introduction

- A method to enhance the early-age strength development of concrete with high SCMs content
  - Decreasing the particle size of SCMs through fine and ultrafine griding



Baláž, P., & Baláž, P. (2008). Mechanochemistry in minerals engineering (pp. 257-296). Springer Berlin Heidelberg

- Examples of ultrafine grinding application
  - Ultrafine grinding of conventional SCMs — Ultrafine slag
  - Mechanical activation of clays & naturally occurring silicate minerals
  - Mechanical activation of non-hydraulic industrial by-products

Objective

- To have a low-Portland cement concrete mixture using a combination of UFS and a medium-grade metakaolin (MK)
  - To prepare & characterize of UFS with D_{50} of ~1 µm
  - To test different combinations of MK-UFS to replace 50 wt% of cement in paste & mortar samples
  - To test concrete with the selected MK-UFS combination

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Methodology

- Materials
  - Cementitious materials
    - ✓ Commercially available cement (GU/GUL), slag and medium-grade MK
    - ✓ **UFS:** Obtained from ultrafine grinding of slag (UFS) in the laboratory
  - Aggregates
    - ✓ Locally available aggregates for concrete

Methodology

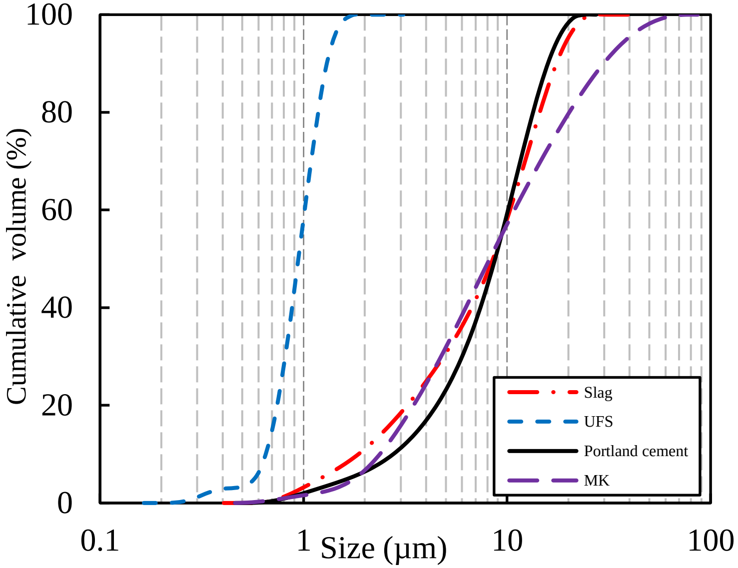
- Concrete (slump: ~100 mm)
  - CM content: 390 kg/m^3
  - W/CM: 0.39
  - Air content: 5-6 %

- Dry-mix Concrete
  - CM content: 380 kg/m^3
  - W/Solid: 6-8 wt%
  - Compaction by Proctor hammer

Mixture	Cement (wt%)	MK (wt%)	UFS (wt%)	Slag (wt%)
Reference	100	-	-	-
C1-M70-U30	50	35	15	-
C1-M70-S30	50	35	-	15

Results – UFS characterization

- Particle size distribution

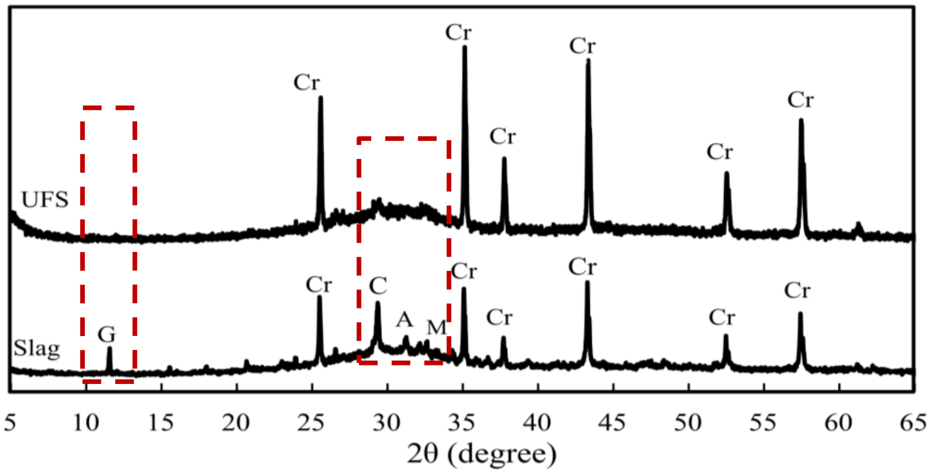


D_{50} of slag: ~8.6 μm

D_{50} of UFS: ~0.9 μm

Results – UFS characterization

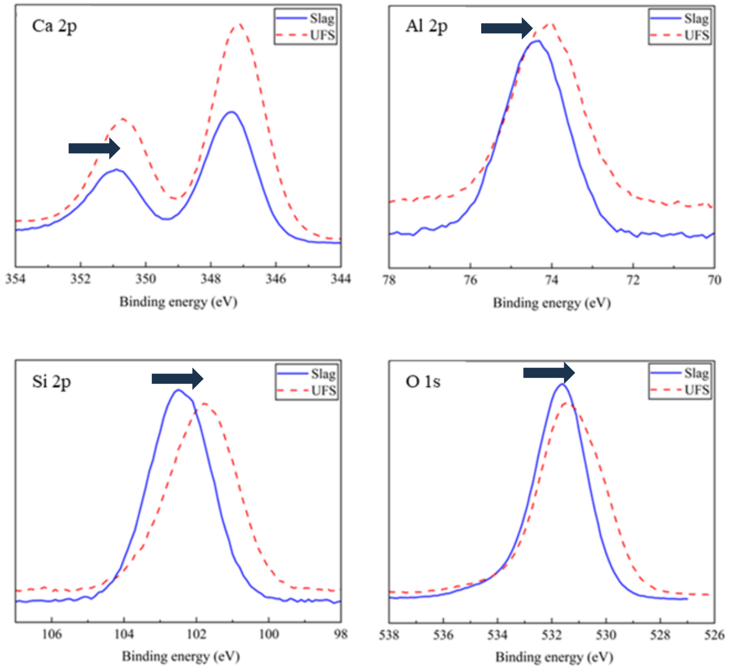
- Crystaline structures



✓ Decrease in the intensity of gypsum, calcite, akermanite, and merwinite peaks

Results – UFS characterization

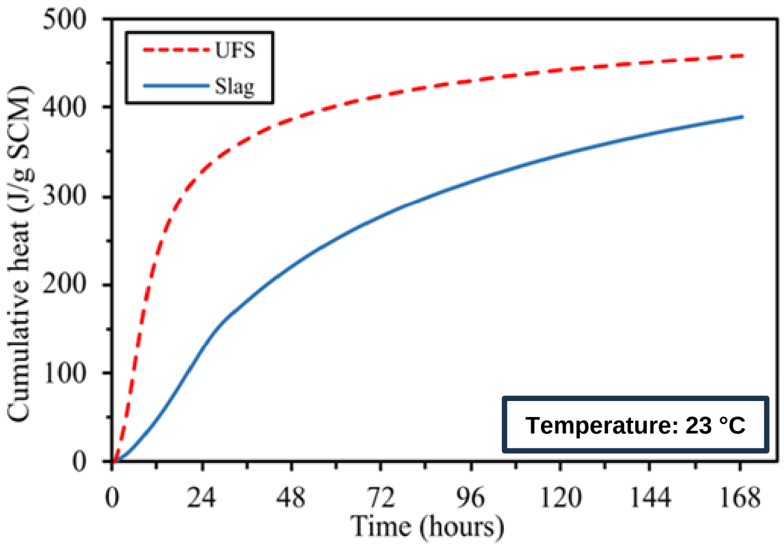
- Binding energy of surface elements with XPS



✓ Decrease in the values of binding energy of elements after ultrafine grinding

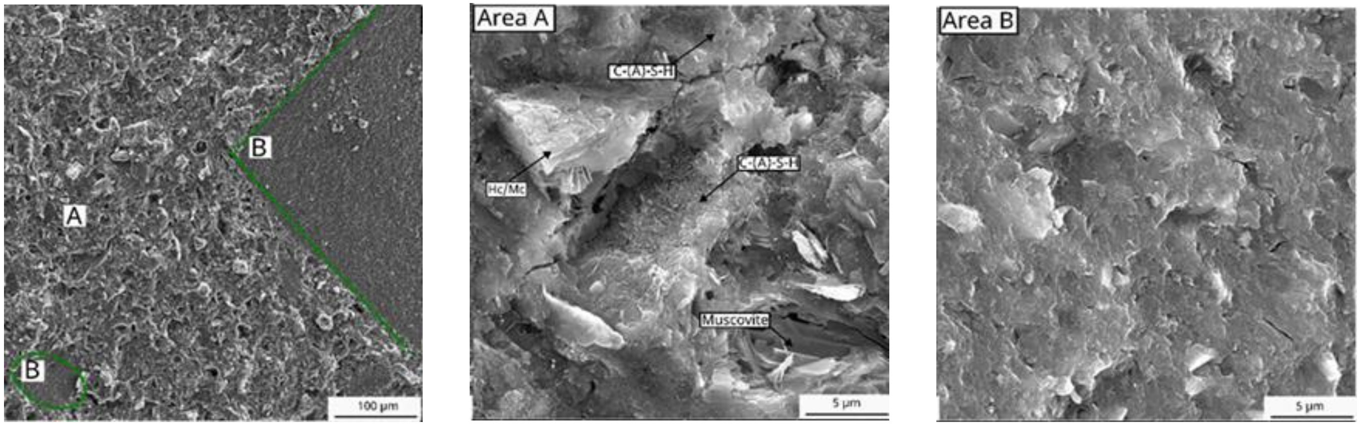
Results – UFS characterization

- Reactivity measurement (R^3 method)



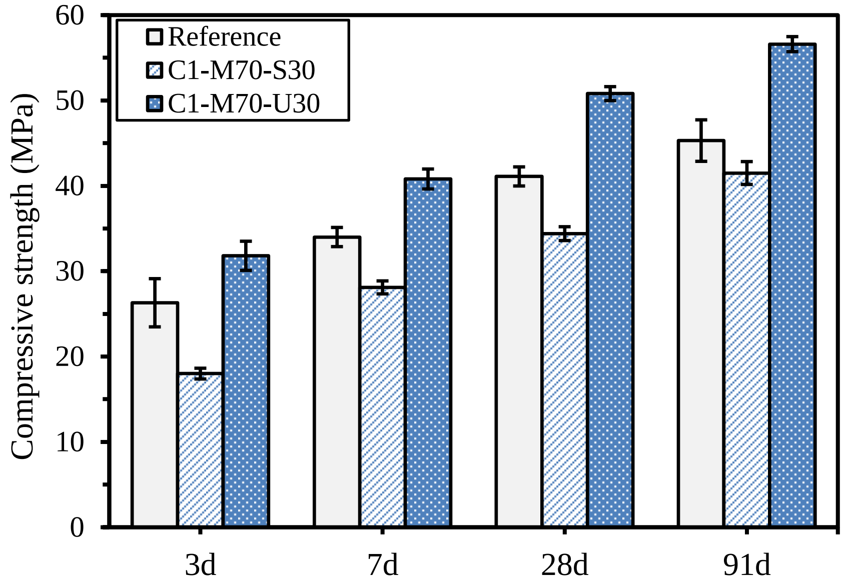
Results – UFS characterization

- Morphology of the pastes with MK-UFS



Results – Concrete

- Compressive strength of concrete

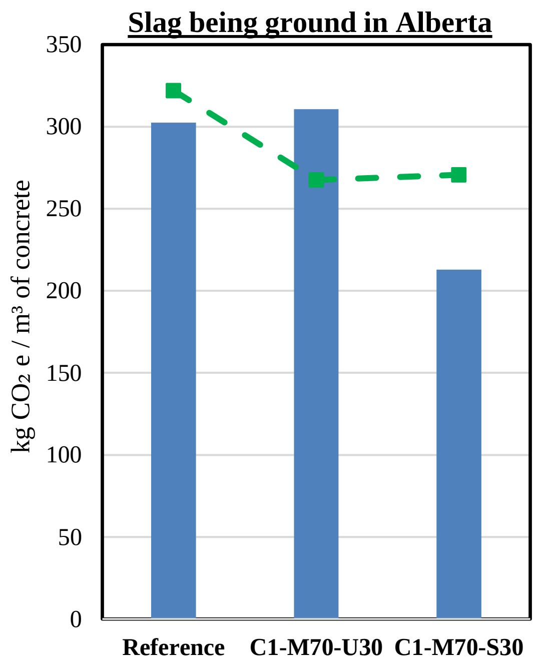


Mixture	SP content (wt% of CM)	Slump (mm)
Reference	0.30	110
C1-M70-U30	0.70	90
C1-M70-S30	0.60	100

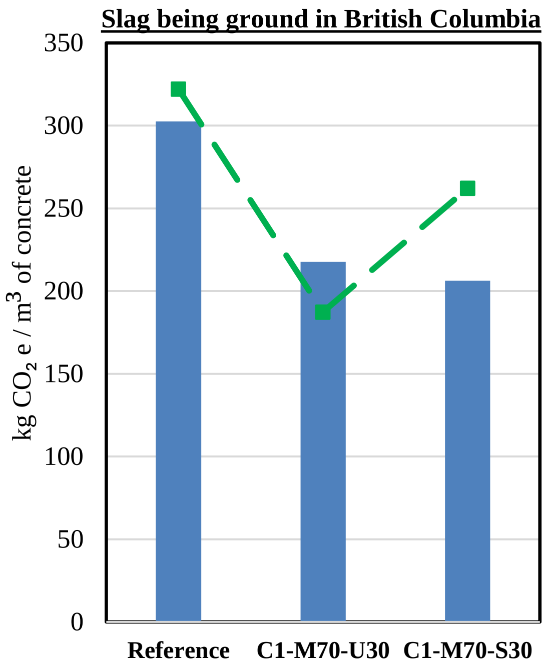
✓ Enhanced strength-development rate of sample with MK-UFS compared to MK-slag

Results – Concrete

- Preliminary LCA results



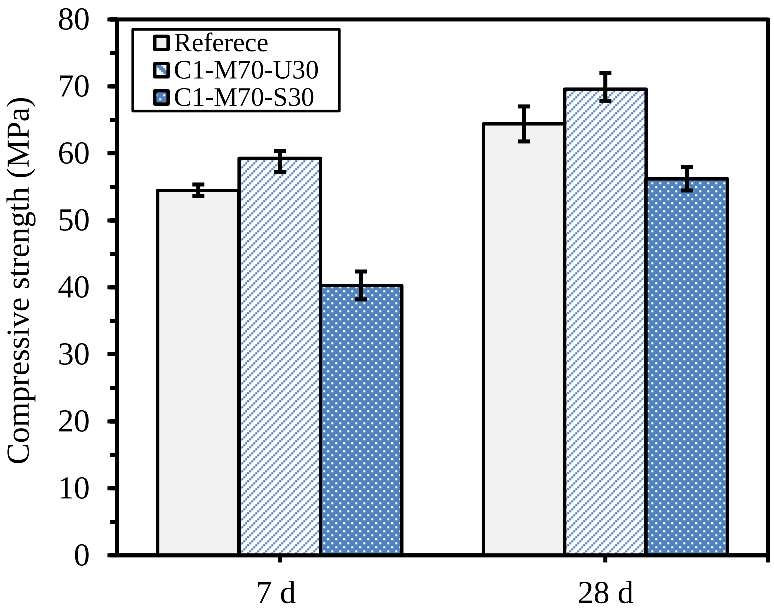
Electricity emission factor:
0.49 kg CO_2 e / kWh



Electricity emission factor:
0.015 kg CO_2 e / kWh

Results – Dry-mix concrete

- Compressive strength of concrete



✓ ~ 16% and 11% higher compressive strength in concrete with 50 wt% MK-UFS compared to that concrete with only cement at 7 and 28 d, respectively

Conclusions

- Ultrafine grinding of slag increased its surface area and amorphous content and decreased the binding energy of its elements, which resulted in a higher reactivity of UFS compared to ordinary slag.

- Combinations of MK and UFS successfully replaced high contents (50 wt%) of Portland cement in concrete samples and provide a comparable early-age strength, and higher late-age compressive strength compared to the concretes with 100 wt% commercial cement.

- The preliminary LCA analysis showed that the concrete with the MK-UFS blend could have a comparable or lower GHG emission per unit strength compared to that made with the slag-MK.

Future research

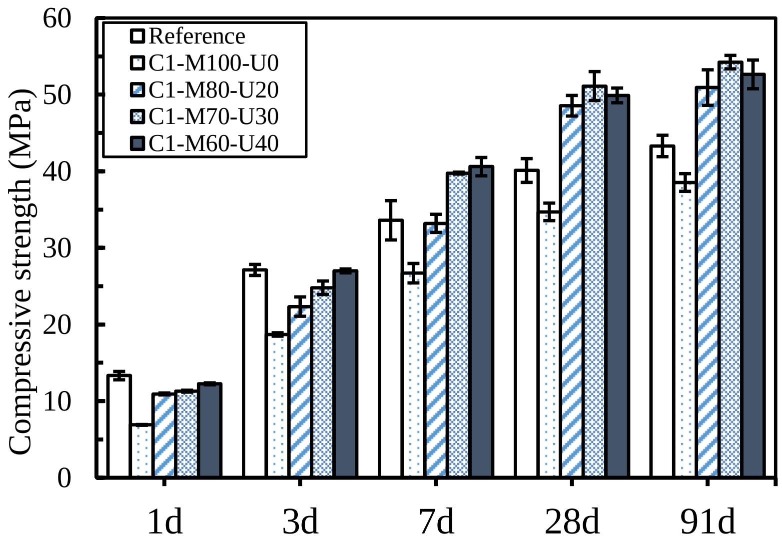
- Optimizing the particle size of other SCMs in blended cements to achieve an equivalent performance in cementitious systems compared to systems prepared with Portland cement
- Identifying the contribution factors to the strength enhancement of cementitious systems containing MK-UFS through studying simplified models
- Assessing durability and volume changes of the so-produced concretes
- Including additional performance parameters such as durability of the concrete mixtures in LCA to provide more insights into potential advantages and disadvantages of using UFS in concrete mixture
- Manufacturing high-strength concrete block masonry units with the proposed mixture

Acknowledgement

- Natural Sciences and Engineering Research Council of Canada (NSERC)
- Canadian Concrete Masonry Producers Association (CCMPA)
- Canada Design Masonry Center (CDMC)
- Innovative Concrete Technologies Laboratory (IConTechLab)
- University of Calgary

Results

- Compressive strength of mortar samples

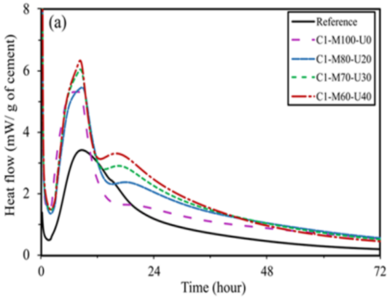


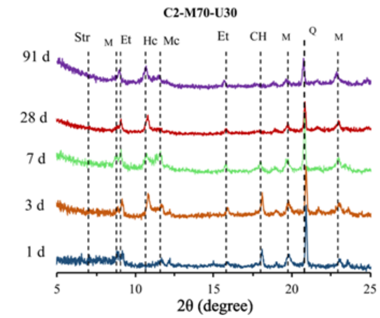
✓ Comparable late-age compressive strength in mixtures with UFS

✓ Higher early-age compressive strength by having more UFS in the mixtures

Results

- Observations in pastes with MK-UFS compared to that with MK only
  - More pronounced changes in the kinetics of cement hydration
  - Higher rate Portlandite consumption
  - Enhanced formation of AFm-carbonate phase





Methodology

- Mortar samples
  - ASTM C109
  - Cementitious materials composition

	Cement (wt%)	MK (wt%)	UFS (wt%)
C1-M100-U0	50	50	0
C1-M80-U20	50	40	10
C1-M70-U30	50	35	15
C1-M60-U40	50	30	20

- Concrete samples
  - CM content: 390 kg/m3
  - W/CM: 0.39
  - Air content: 5-6 vol%
  - Target 28-d strength: 40 MPa
  - C1-M70-U30
  - C1-M70-S30