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# Emerging Technologies

**ACI Fall 2012 Convention**
**October 21 – 24, Toronto, ON**

ACI WEB SESSIONS

**Dr. Medhat H. Shehata** is a Professor in the Department of Civil Engineering at Ryerson University, Ontario, Canada. Dr. Shehata has 25 years of industrial and academic experience pertaining to construction material. His areas of expertise include properties, deterioration mechanisms and long-term performance of concrete, development of test methods and standards, construction sustainability and green buildings, recycling of construction and industrial wastes, and development of new construction materials. Dr. Shehata is the current Chair of the Engineering mechanics and Materials of the Canadian Society for Civil Engineering. He is also a member of various international technical committees including Canadian Standards Association, CSA A23.1 and A23.2, the Technical Subcommittee on Alkali-Aggregate Reaction of CSA, and Committee C. 09, Concrete and Aggregate and subcommittee 09.26, Chemical Reaction of the American Society for Testing and Materials (ASTM).

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## Alkali Reactivity of Reclaimed Concrete Aggregate: Evaluation, Testing and Preventative Measures

Medhat Shehata, Chris Christidis, Waleed Mikhaiel, Robert Johnson, Mohamed Lachemi
Ryerson University
Toronto, Ontario, Canada

Chris Rogers
Consultant, Ontario, Canada

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## Reclaimed Concrete Aggregate (RCA)

Reclaimed or recycled concrete aggregate is produced from processing of demolished concrete structures or returned-to-plant concrete.

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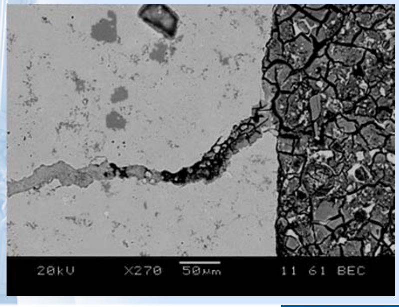


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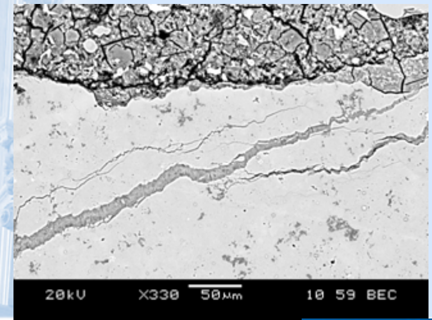


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## Problem Definition

- In Canada, RCA has been used with success as granular base for pavements
- The use of RCA in some construction applications such as Controlled Low Strength Materials (CLSM) is under consideration
- The lack of availability of natural aggregates in some locations may push for the use of RCA in structural concrete

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## Problem Definition

- If the RCA or percentage of it was produced from structures affected by ASR, will the new concrete suffer deterioration?
- Are there preventive measures? Are these preventive measures “practical”?
- Is there a way to ”safely” use RCA even if part of it is affected by ASR?
- Are there accelerated test methods to evaluate preventive measures?

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## Reactivity of RCA and Preventive Measures

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## Materials
## Reactive Aggregates

- **RCA:** a concrete block placed in 1991 with (GUPC) and highly reactive siliceous limestone coarse aggregate from Ottawa, Ontario (Spratt).
- **Virgin Reactive Aggregate**: The same aggregate used in the test block

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## Materials
## Cementing Material

- Low-Alkali GU PC, $Na_2O_e$ = 0.56%
- High-Alkali GU PC, $Na_2O_e$ = 0.96%
- Silica Fume
- Slag
- F-LA: CaO = 4.4% $Na_2O_e$ = 1.95%
- F-HA: CaO = 6.4% $Na_2O_e$ = 4.30%
- CI-LA: CaO = 17.0% $Na_2O_e$ = 2.10%
- CH-LA: CaO = 28.7% $Na_2O_e$ = 2.16%
- Lithium Nitrate

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## Experimental Techniques

- Concrete Prism Test
- Accelerated Mortar Bar test
- Concrete Microbar Test
- Scanning Electron Microscopy and Energy Dispersive X-ray analysis

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## Experimental Techniques

- **Concrete Prism Test**
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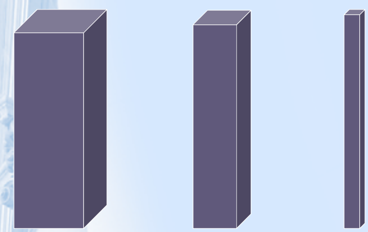
## Test Methods

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## Test Methods

| | Concrete Prism Test | Accelerated Mortar Bar Test | Concrete Microbar Test |
|---|---|---|---|
| Standard | ASTM C 1293 | ASTM C1260 and C 1567 | RILEM AAR 5 |
| Mixture | Concrete | Mortar | Paste + Coarse aggregate |
| Dimension | 75 X 75 X 285 mm | 25 x 25 x 285 mm | 40 x 40 x 160 (or 285) mm |
| Aggregate | 19 .0– 4.75 mm + sand | Sand fractions < 4.75 mm | Stones 4.0 to 8.0 mm (no sand) |
| Soaking solution | No | Yes | Yes |
| Duration | 1 or 2 years | 14 days | 14 to 28 days |
| Temperature | 38 C | 80 C | 80 C |

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## Test Methods


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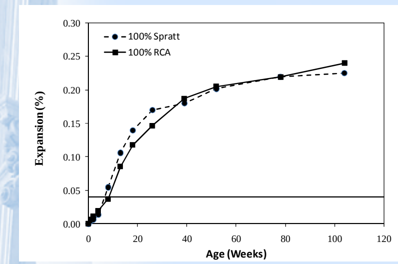
## Reactivity of RCA - Phase 1

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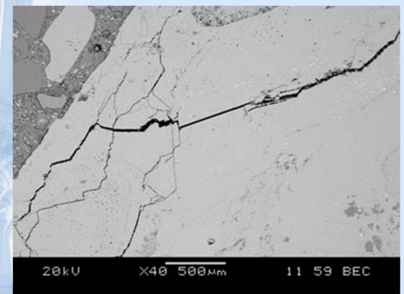
## Reactivity – Aggregate Processing

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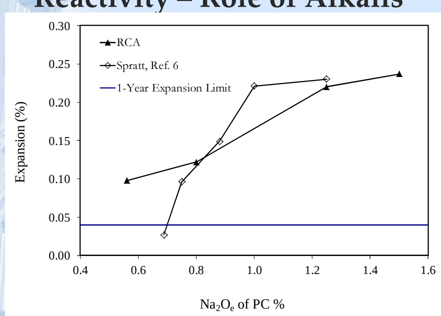
## Reactivity – Role of Alkalis

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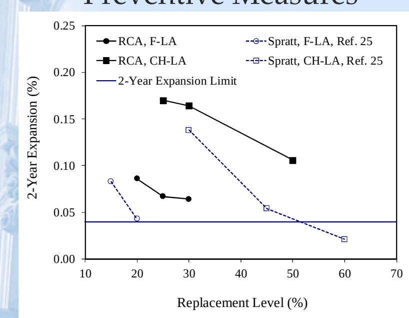
## Preventive Measures

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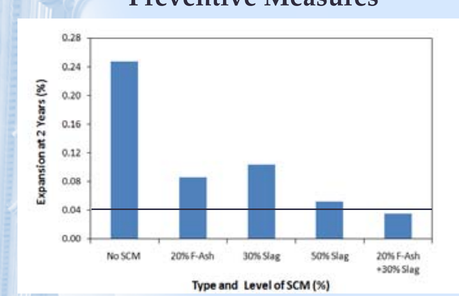


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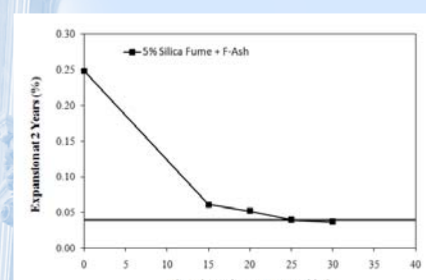


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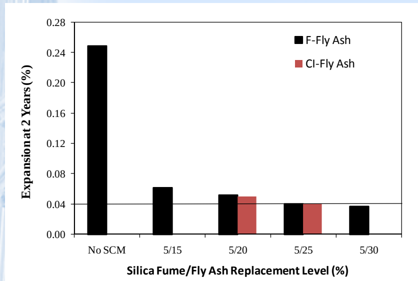


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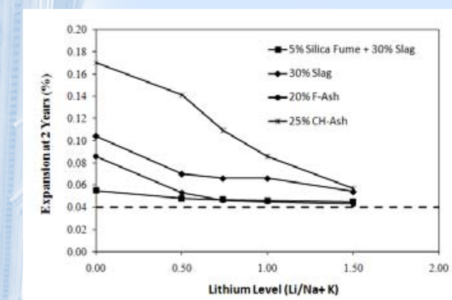
## Preventive Measures

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## Aggregate Dilution: A practical Mitigation Approach

Most concrete applications would include blends of RCA and natural aggregates to reduce volume change (shrinkage) and maintain other durability aspects.

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## Aggregate Dilution: A practical Mitigation Approach

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Most concrete mixtures include one of more types of SCM

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## Aggregate Dilution: A practical Mitigation Approach

Most concrete applications would include blends of RCA and natural aggregates to reduce volume change (shrinkage) and maintain other durability aspects.

Most concrete mixtures include one of more types of SCM

Will “practical’ level of SCM mitigate ASR in concrete with blends of reactive RCA and non-reactive natural aggregate?

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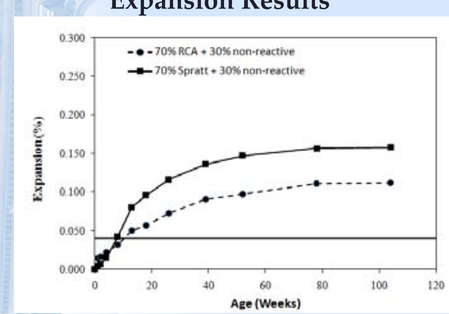
## Expansion Results

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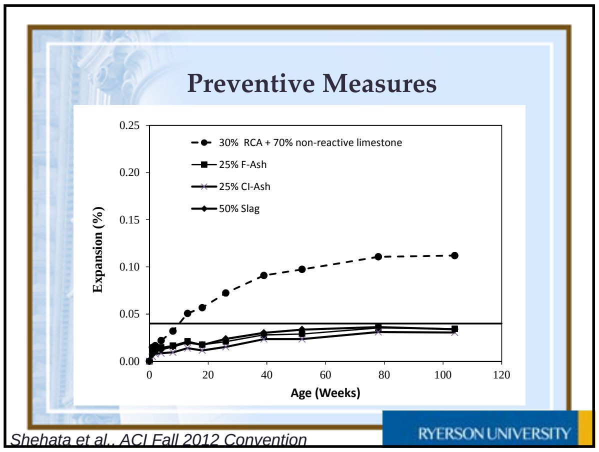
Preventive Measures
Expansion (%)
Age (Weeks)
30% RCA + 70% non-reactive limestone
25% F-Ash
25% CI-Ash
50% Slag
0.00
0.05
0.10
0.15
0.20
0.25
0
20
40
60
80
100
120
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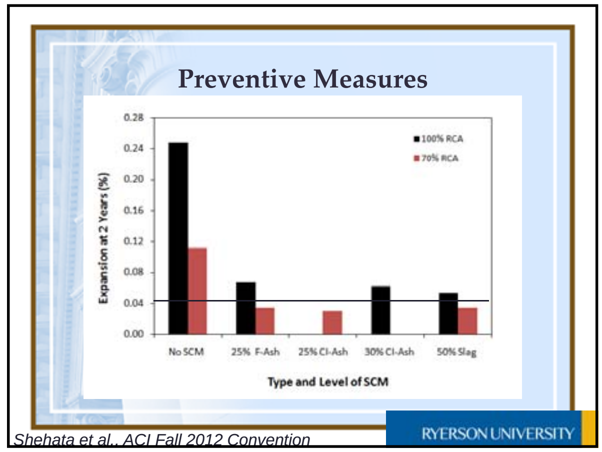
Preventive Measures
Expansion at 2 Years (%)
100% RCA
70% RCA
No SCM
25% F-Ash
25% CI-Ash
30% CI-Ash
50% Slag
Type and Level of SCM
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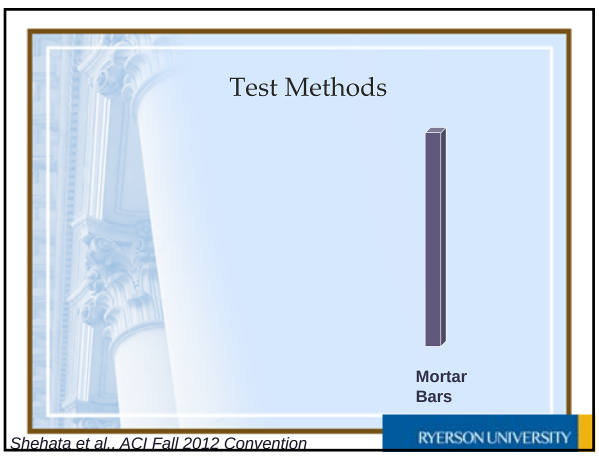
Test Methods
Mortar
Bars
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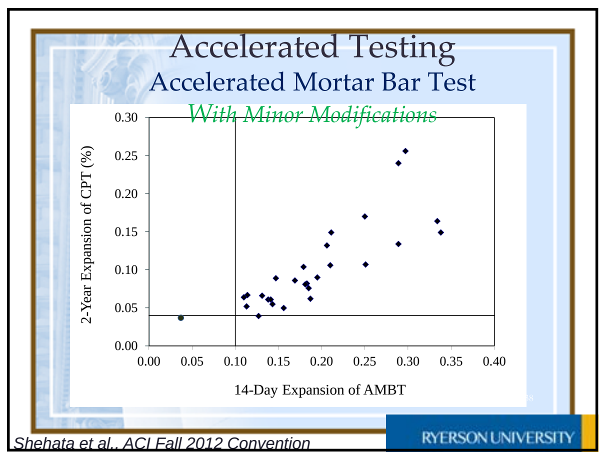
Accelerated Testing
Accelerated Mortar Bar Test
With Minor Modifications
2-Year Expansion of CPT (%)
14-Day Expansion of AMBT
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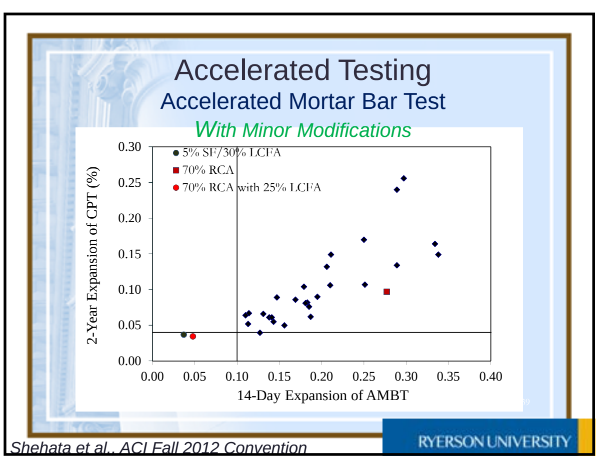
Accelerated Testing
Accelerated Mortar Bar Test
With Minor Modifications
5% SF/30% LCFA
70% RCA
70% RCA with 25% LCFA
2-Year Expansion of CPT (%)
14-Day Expansion of AMBT
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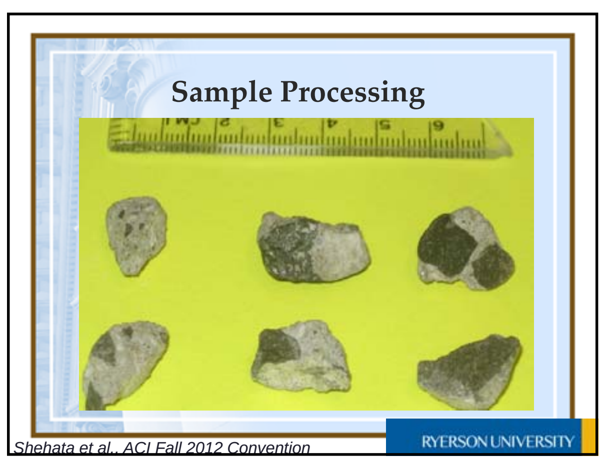
Sample Processing
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## 4.75 mm to 2.36 mm

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## Sample Processing


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## AMBT: Interlab Study
### Different Types of RCA from Test Blocks

| Aggregate | AMBT 14d exp,% | CPT 1-year exp,% | Reactivity level | Block Age | Average Expansion % |
|---|---|---|---|---|---|
| Alberta Gravel | 0.360 | 0.090 | Moderate | 14 years | 0.423 |
| Springhill Limestone | 0.463 | 0.217 | High | 16 Years | 0.563 |
| Potsdam Sandstone | 0.090 | 0.130 | High | 14 Years | 0.193 |
| Bernier Limestone | 0.173 | 0.069 | Moderate | 14 Years | 0.092 |

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## AMBT: Interlab Study
### Different Types of RCA from Test Blocks

| Aggregate | Location | Rock Type | AMBT 14d exp,% | CPT 1-year exp,% | Reactivity level |
|---|---|---|---|---|---|
| Alberta Gravel | Calgary (Canada) | Gravel (sandstone, limestone, quartzite and mixed volcanics) | 0.360 | 0.090 | Moderate |
| Springhill Limestone | Fredericton (Canada) | Crushed greywacke | 0.463 | 0.217 | High |
| Potsdam | Montreal (Canada) | Siliceous sandstone | 0.090 | 0.130 | High |
| Bernier Limestone | St-Jean sur-le-Richelieu (Canada) | Argillaceous limestone | 0.173 | 0.069 | Moderate |

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## AMBT: Interlab Study
### Different Types of RCA from Test Blocks

| RCA Replacement Level and Aggregate Type | Number of Samples (Bars) | Average Expansion (%) | Coefficient of Variation (%) | Precision Boundary Limits (43% Above or Below Mean Expansion) | | |
|---|---|---|---|---|---|---|
| | | | | Lower Expansion Boundary (%) | Upper Expansion Boundary (%) | Number of Outliers |
| 25% Alberta | 24 | 0.20 | 11.5 | 0.12 | 0.29 | 0 |
| 50% Alberta | 24 | 0.28 | 11.5 | 0.16 | 0.40 | 0 |
| 100% Alberta | 12 | 0.31 | 5.8 | 0.18 | 0.45 | 0 |
| 25% Bernier | 12 | 0.08 | 22.8 | 0.04 | 0.11 | 0 |
| 50% Bernier | 24 | 0.09 | 8.5 | 0.05 | 0.13 | 0 |
| 100% Bernier | 12 | 0.11 | 17.5 | 0.06 | 0.16 | 0 |
| 25% Potsdam | 12 | 0.05 | 27.5 | 0.03 | 0.07 | 0 |
| 50% Potsdam | 12 | 0.06 | 7.3 | 0.04 | 0.09 | 0 |
| 100% Potsdam | 12 | 0.07 | 10.4 | 0.04 | 0.10 | 0 |
| 25% Springhill | 12 | 0.20 | 16.5 | 0.11 | 0.28 | 0 |
| 50% Springhill | 12 | 0.29 | 7.9 | 0.16 | 0.41 | 0 |
| 100% Springhill | 36 | 0.32 | 20.2 | 0.18 | 0.46 | 0 |

Source: Adams et al. 2012

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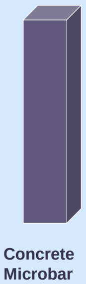
## Test Methods

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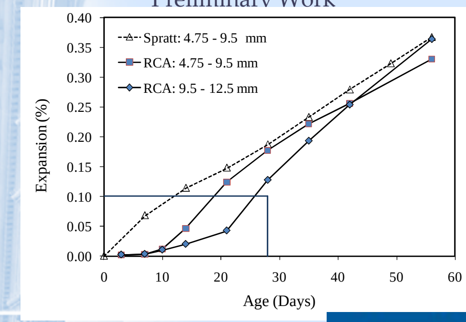
## Concrete Microbar test
Preliminary Work

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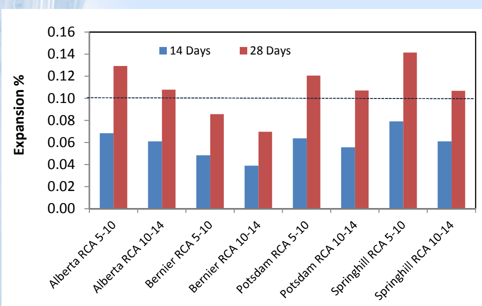


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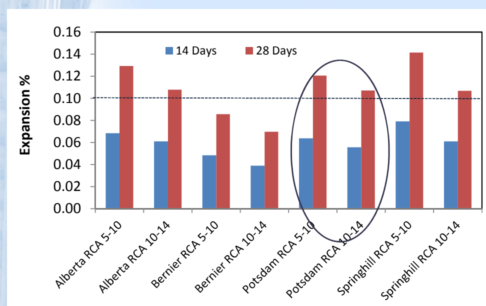


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## Conclusions

- Mitigating expansion in concrete containing reactive RCA could be achieved using ternary blends of silica fume and low or intermediate calcium fly ash of alkali content ≤ 2.0% $Na_2O_e$.
- Ternary blends of 20% Type F fly ash and 30% slag was also effective in mitigating the expansion in concrete with 100% RCA used as coarse aggregate.

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## Conclusions

- The use of lithium nitrate with SCM reduced the expansion of concrete; however, the levels of investigated lithium and SCM were not enough to limit the expansion to < 0.04% at 2 years.
- Blending the reactive RCA with non-reactive coarse aggregate reduced the expansion compared to concrete with 100% RCA used as the coarse aggregate.

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## Conclusions

- Practical levels of SCM's (25% fly ash of CaO < 20% and 50% slag) were effective in mitigating the expansion in concrete with reactive RCA blended with 30% non-reactive natural stones.
- The concrete microbar test showed promising results in terms of predicting reactivity of RCA. More work is needed to investigate the capacity of the test to evaluate preventive measures.

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