





American Concrete Institute®  
Advancing concrete knowledge

## Emerging Technologies

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

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WEB SESSIONS

**Marc Jolin** is a Full Professor in Laval University, Quebec city, Canada. His main research interest have evolved around shotcrete for the last 15 years. He is an active member of the ACI 506 Shotcreting committee and chairman of the ACI C660 Shotcrete Nozzleman Certification program committee as well.

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Centre de recherche sur les infrastructures en béton  
Montréal • Québec • Sherbrooke


## Shotcrete R&D

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## Industrial Chair - History


- In the late 80's, the MTQ was actively looking at shotcrete as a repair methods for its structures
  - It had a limited success, and realized some R&D was needed to solve a few issues (e.g. cracking, durability)
  - A few M.Sc. projects were undertaken
- In 1991, it became clear that shotcrete was there to stay, and a more organized research effort was envisioned: an *Industrial Chair* was put together

## Industrial Chair - History

*NSERC Industrial Chair on Shotcrete and Concrete Repairs (1994-2004)*

*NSERC Industrial Chair on Durable Repair and Optimized Maintenance of Concrete Infrastructures (2006-2011)*

## Shotcrete

- Early on, shotcrete raised many questions on:
  - Mix design performances (durability, mechanical properties and bonding)
  - Placement techniques ( $f_c$ (mix design)).
  - Jobsite and long term results
- Objective: develop knowledge to increase the confidence of the user and increase use in general of shotcrete



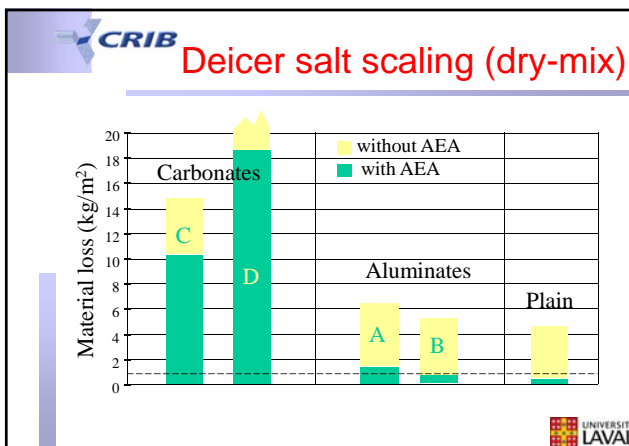
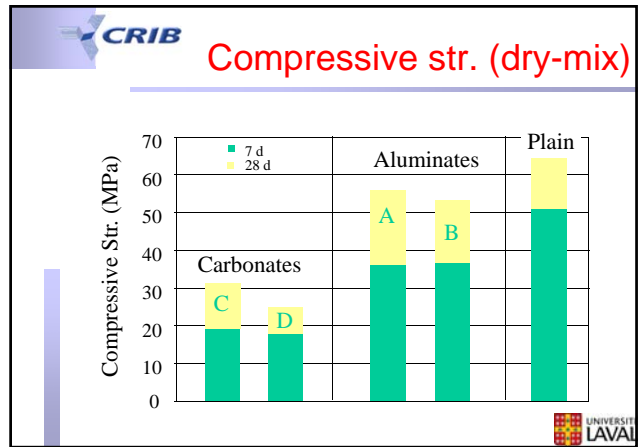
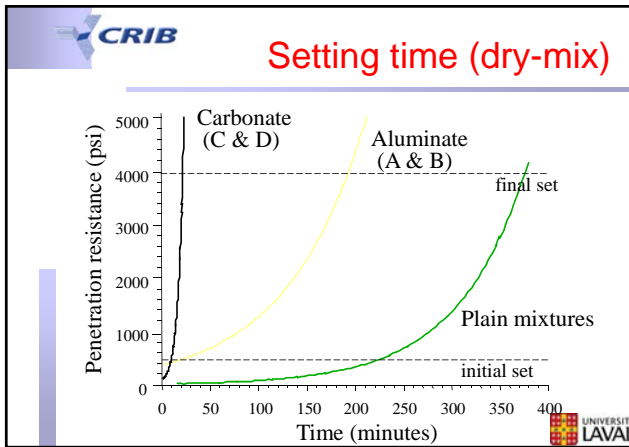
**CRIB** **Mixture design**

- Accelerators (dry and wet-mix)
- Air entraining admixtures
- Shrinkage reducing admixtures
- Internal curing agents
- Supplementary materials et replacements
  - Fly ash
  - Ternary binders

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**Set accelerators ...?**

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**CRIB** **Set accelerators in dry-mix shotcrete**

**Recommendations**

- In dry-mix shotcrete, the chemical family of a set accelerator is the main selection criterion
  - Aluminates based powders are the only one recommended for repairs exposed to aggressive environments
  - Carbonate based are especially efficient in the mining environment, where short term properties are very important

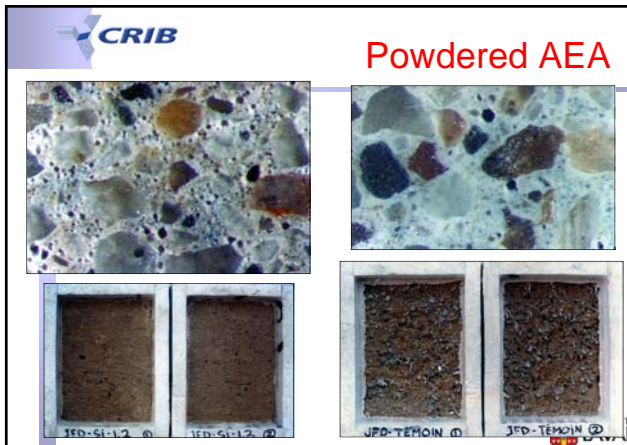
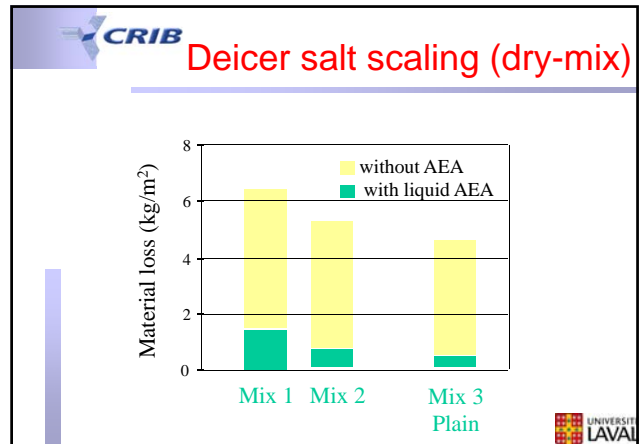
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**CRIB** **Air entraining admixtures**

**Objectives**

- Confirm the positive effect of AEA on frost durability in dry-mix shotcrete
- Study the option of using AEA in the powder form
  - Better control in pre-bagged material

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**CRIB** **Air entraining admixtures**

**Results & Observations**

- Necessity of AEA in dry-mix shotcrete exposed to freezing environments is confirmed
- Powdered AEA are equivalent if not better:
  - Spacing factor usually below 200 µm
  - Dosage (by mass) << 1% of binder by mass

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**CRIB** **Placement methods**

- High initial air content concept
- Shooting consistency
- Nozzlemen certification
- Reinforcement encapsulation
- Multi-layer application

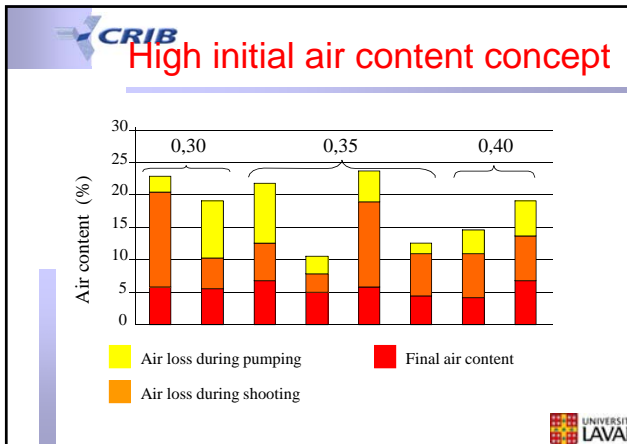
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**CRIB** **High initial air content concept**

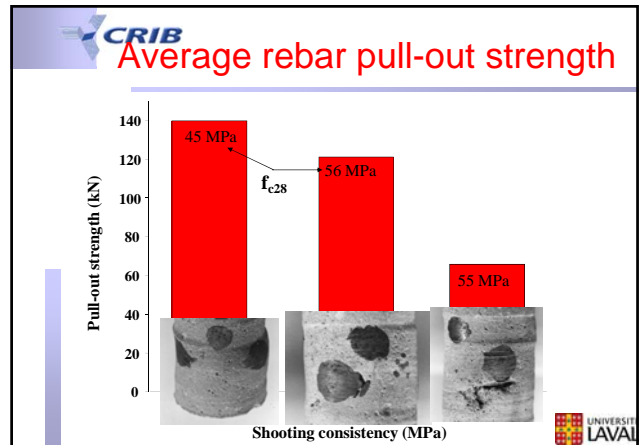
**Objectives**

- Use air bubbles to improve workability of the fresh concrete (good pumpability) while generating a “slump killer” effect during compaction of the material by pushing out the air bubbles, thus creating a stiffer material (good shootability)
- Confirm the usability of the concept on a job site

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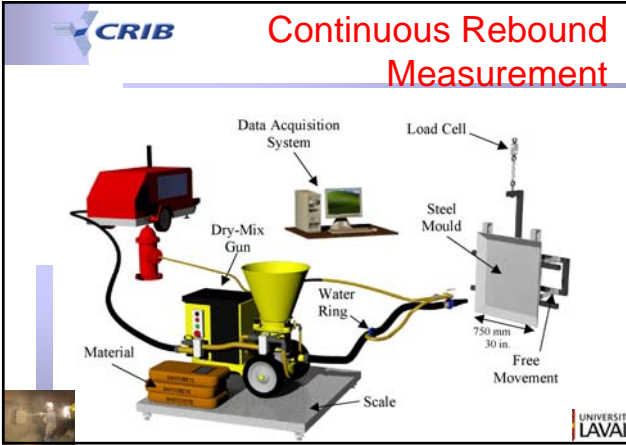


- ### High initial air content concept
- Results & Observations**
- The concept is applicable on regular job sites (and has been for 15 years in many areas)
  - In-place* air content is always sufficiently *low* to promote good compressive strength
  - In-place* spacing factor extremely good, typically < 200 μm
  - Helps avoid set accelerators in "normal" placing conditions**
- Recommendation:** Use it !



- ### Nozzlemen certification
- Nozzlemen certification program created in 1997 for Quebec DOT
  - Strong implication from the Industrial chair on the ACI shotcrete nozzlemen certification program
  - ACI "Shotcrete Nozzlemen Certification" available since 2001
  - Adopted by Quebec DOT in 2002

- ### Recent years R&D
- Inform and capture your interest in *shotcrete research!*
    - Our lab...
      - ... or the dustiest lab in North America
    - Pumping...
      - ... why a pizza is a good comparison
    - Durability and service life...
      - ... of course it's as good as cast in-place!
    - Ultra High Early Strength
      - 10 MPa in minutes...
    - Placement...
      - ... particles flying at 500 km/h, I swear !



**CRIB**

## Service Life of Shotcrete

Contributors: Louis-Samuel BOLDUC  
Patrick POWER  
Benoît BISSONNETTE

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## Background

- Shotcrete shows more voids than regular concrete
  - Absorption values and volume of permeable voids are higher than that generally found for similar concrete
  - however...
- Shotcrete is generally reported as having an excellent durability

**CRIB**

## Background

- Specification often calls for a maximum value of absorption for shotcrete (ASTM C642)
  - Which is the source of animated discussion both around the construction site and technical committee meetings !

Sprayed Concrete Quality	Permeable Void Volume (%)	Boiled Absorption (%)
Excellent	< 14	< 6
Good	14 – 17	6 – 8
Fair	17 – 19	8 – 9
Marginal	> 19	> 9

[Morgan et al., 1987]

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## Challenge & Objective

- Predict long term durability of various types of shotcrete
  - Placement process changes the in-place composition and has an impact on the consolidation level
- Generate data on *shotcrete* transport properties
  - And compare them to regular cast in-place concrete!

Capillary absorption -surface tension-

Water diffusion -RH-

Water permeability -pressure-

Ionic diffusion -concentration-

Reinforcing Steel Corrosion

Abrasion and Chemical

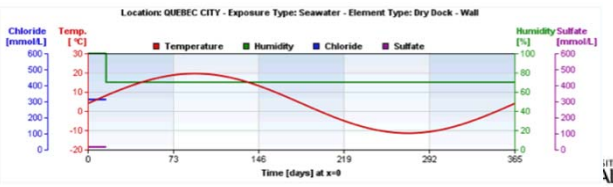
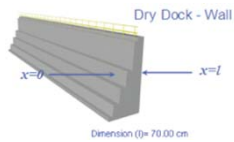
Freeze-Thaw Damage, Temperature Gradients, Humidity Gradients

Alkali-Aggregate Reaction Chemical Decomposition of Hydrated Cement

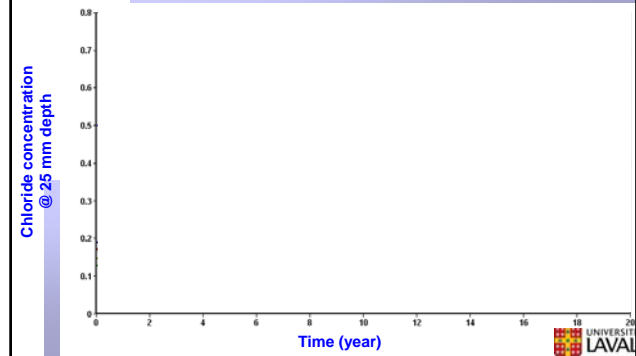
Concrete Reinforcing Steel

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## Service Life Prediction



## Service Life Prediction



## Discussion

- Mix design plays an important role
- The *shotcrete placement method* is creating a very unique and special type of concrete !

## Placement of shotcrete

Contributors: Nicolas GINOUSE  
Benoît BISSONNETTE

**CRIB** **Background**

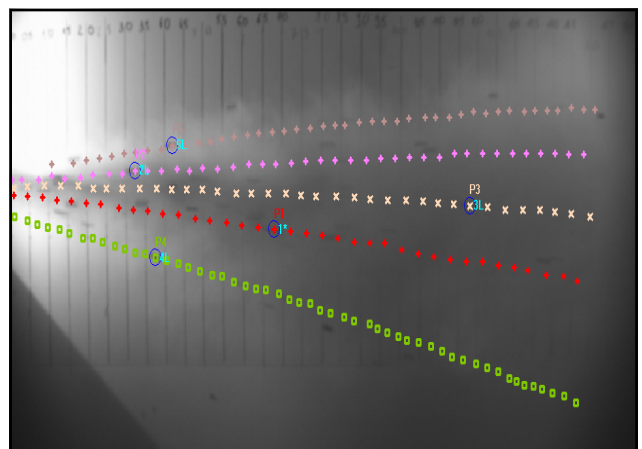
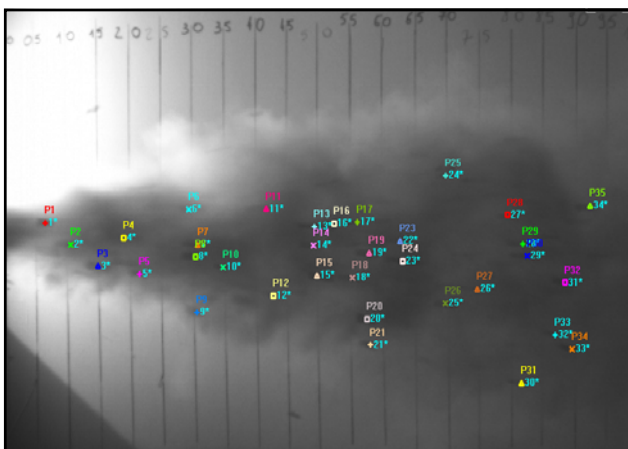
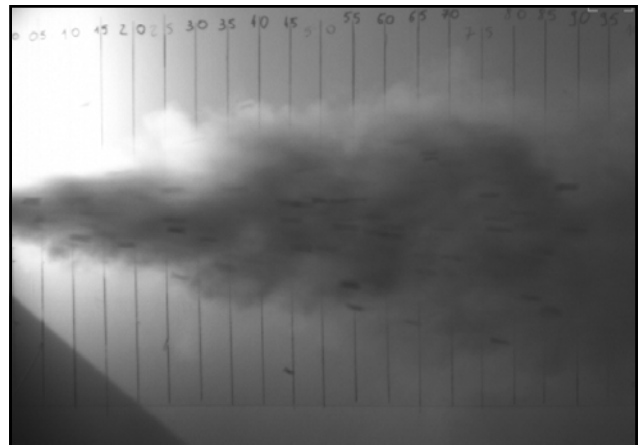
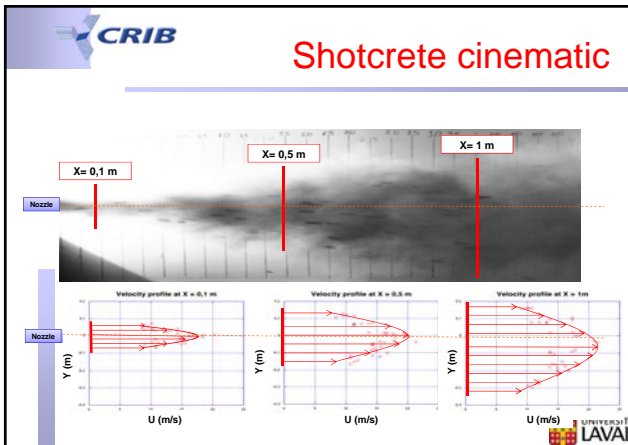
- Study of particles transport

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**CRIB** **Background**

- A wide range of particle velocities are reported in literature
  - Stewart (1933)  
220-330 MPH (Gunite)
  - Austin and Robins (1995)  
65-135 MPH (dry-mix)  
25-65 MPH (wet-mix)
  - Armelin high-speed filming (1997)  
11- 60 MPH
- No characterization of the entire flow of particle out of the nozzle

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**CRIB** Shotcrete cinematic

Wet-Mix – 200cfm- 100 cm - 36 in

nozzle

Mass (kg) / g

Experimental data : Captured weight per unit of time

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**CRIB** Objective & Methodology

- Study Rebound (through Armelin's model 1997)

Impact point

Particle's trajectory

Particle tracking during the impact

Impact model (Armelin, 1997)

⇒ **Verify and enhance rebound model accuracy**

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**CRIB** Discussion

- Perspective of this study
  - Effect of equipment on *material exit velocities, velocity profiles and energy profiles*
    - Understanding and describing the flow of material
  - Effect of *material flow characteristics* on:
    - rebound
    - in-place compaction and composition
    - in-place mechanical properties**
    - durability**

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**CRIB** Concluding remarks

- Research in shotcrete is strong !
- Many subjects are of interest:
  - pumping, placement, durability, etc.
- Look for it!

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**CRIB** Special thanks...

- This type of research requires strong support from the industry

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**CRIB** Contributors

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*Thank you !*

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You may want to visit [www.shotcrete.org](http://www.shotcrete.org) !