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Introduction of Revised Specification for Shotcrete and Other Shotcrete Development

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Montréal • Québec • Sherbrooke

Service life prediction of shotcrete

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Background of research work

- In recent decades, economical and environmental changes have greatly influenced the construction industry
  - Today, owners and specifiers ask for strong, green and durable materials, and they need to know how long they can expect the performance to remain acceptable
- This has brought the concept of *service life prediction*

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Background of research work

- Concrete community adapted to these new challenges
  - Performance based specification
  - Predictive models
- While important data has been generated for regular concrete, very little information is available on the service life of shotcrete *specifically*

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Background of research work

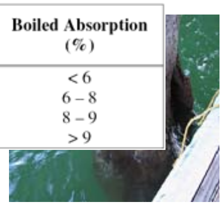
- Shotcrete is not regular concrete
  - Boiled water absorption and volume of permeable voids are higher than that generally found for similar concrete
  - Compaction and mixing energy is significantly different compared to cast-in-place concrete
  - However…
- Shotcrete is generally reported as having excellent durability

Background of research work

- 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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Background of research work

- Researchers know that contaminants ingress in the concrete porosity through different transport mechanisms
  - Permeability
  - Moisture diffusivity
  - Ionic diffusivity
  - Capillary Absorption
- Every mechanism refers to a distinct physical phenomenon
- The environmental exposure should be considered to decide which test is relevant

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Background of research work

There was a clear need to answer these questions and study shotcrete behaviour

A series of R&D projects were undertaken on this subject at Laval University to address this problem and inform the shotcrete community

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Objectives

- Generate data on *shotcrete* transport properties
  - And compare them to regular cast in-place concrete
- Offer guidelines for engineers to help them specify relevant material information
  - Apart from compressive strength, what else should we be controlling shotcrete quality for:
    - Boiled water absorption ?
    - Rapid chloride permeability test ?

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Specific Objectives

- Phase 1 (2007-2009) - Exploration
  - Perform a complete characterization of several conventionally placed and sprayed concrete mixtures
  - Explore the relationships between BWA and …
    - mixture design?
    - shooting parameters?
    - RCPT?
  - Generate preliminary data on *STADIUM®* software for service life prediction

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Specific Objectives

Based on results from Phase 1…

- Phase 2 (2011-2013)
  - Perform a complete characterization of more focused mixture selection
  - Confirm (or invalidate) data from phase 1
  - Perform refined analyses using a service life prediction software

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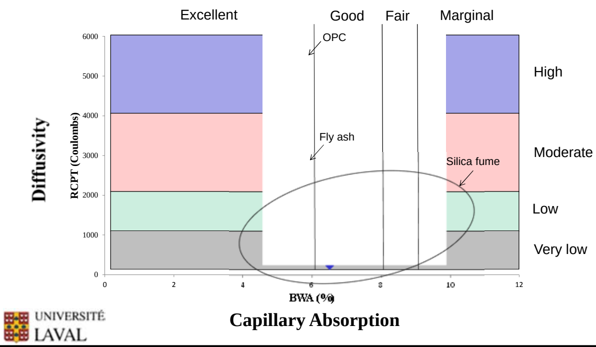
In Phase 1, several shotcrete mixtures were placed and characterized in Laval University's shotcrete laboratory.

The main element studied was the relevance of specifying BWA test as a durability criterion

To achieve this objective, BWA results were compared to RCPT results…

Phase 1 - Results



Service life prediction

Durability?

- From previously exposed information, it appears that BWA poorly correlates with RCPT
- Also, it must be emphasized that RCPT does not help owners and engineers to estimate the service life of their concrete infrastructures…
- The next step in our investigation was therefore to answer the following question:

  How can we predict shotcrete service life?

Service life prediction

- Numerous models are available to predict the service life concrete infrastructures
- There is an increasing trend in the industry to include service life requirements in specifications
  - Contract documents can contain clauses such as: *concrete shall have a service life of … years*
    - Panama Canal
    - Multilevel parking structures
    - DOT rehabilitation projects
    - …

Service life prediction

- However, very little information has been published on this subject regarding shotcrete… and the problem was addressed in this project
  - Tests were performed on several shotcrete mixtures
    - Migration test (ASTM C1202 modified)
    - BWA (ASTM C642)
    - Drying test
    - Pore solution extraction
  - Service life modeling was performed with STADIUM ® software[1] on tested mixtures

[1] Developed by SIMCO TECHNOLOGIES

STADIUM® software

- STADIUM ® is a numeric tool that predicts the ingress of corrosive species in cementitious materials
- Inputs required to perform service life simulations…
  - Test results
  - Material properties
  - Environmental exposure
- Inputs are computed in a multi-ionic model that considers
  - Mass and energy transport equations
  - Chemical equilibrium equations

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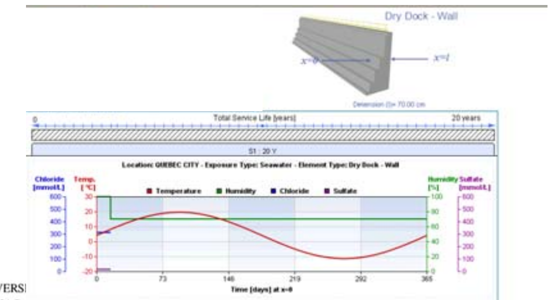
Service Life Prediction

- Simulation example (STADIUM ®)



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Service Life Prediction

- Comparison of 4 mixtures

1. Control (SUMMA): W/Cm=0,45 – Type GU+8% SF
2. Dry-mix shotcrete: W/Cm=0,51 – Type GU+10% SF
3. Wet-mix shotcrete: W/Cm=0,40 – Type GU+8% SF
4. Dry-mix mortar: W/Cm=0,47 – Type GU+12% SF

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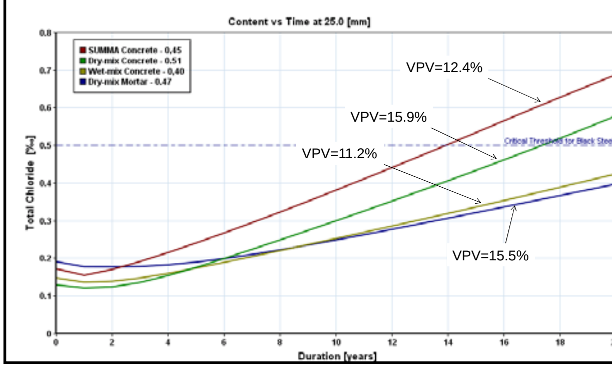
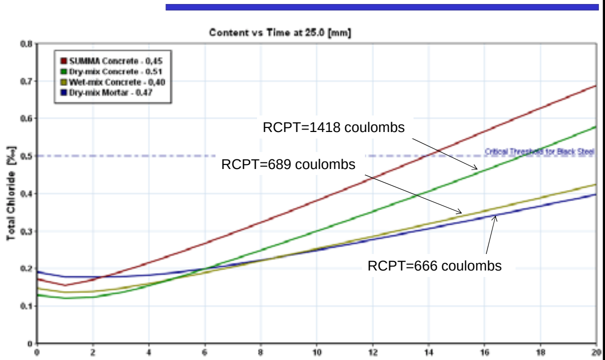
Service Life Prediction



Service Life Prediction



Phase 2 - Current project

Based on results from Phase 1, a new experimental campaign was launched to further investigate the durability and service life assessment of shotcrete

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Phase 2 - Methodology

- Shotcrete mix designs

		OPC	SF	FA	ACI#1	ACI#2	Dry-mix	Wet-mix
Mix 1	D-M1	X			X		X	
Mix 2	D-M2	X			X		X	
Mix 3	W-M3	X			X			X
Mix 4	D-SF	X	X			X	X	
Mix 5	W-SF	X	X			X		X
Mix 6	D-SF+FA	X	X	X		X	X	
Mix 7	D-control	X				X	X	
Mix 8	W-control	X				X		X

Mortar (Mix 1–3), *Silica fume* (Mix 4–5), *Ternary* (Mix 6), *Control* (Mix 7–8)

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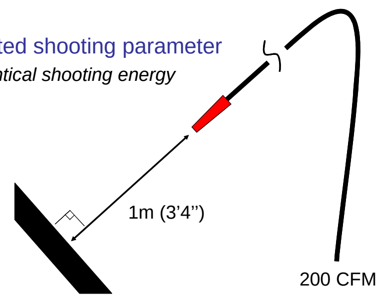
Phase 2 - Methodology

- Selected shooting parameter
  - *Identical shooting energy*



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Phase 2 - Methodology

- Batching process

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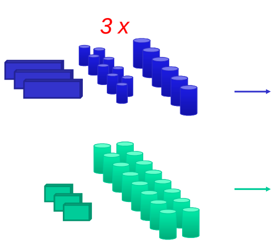
Phase 2 - Methodology

- Testing program



Standardized tests
- ASTM C1604 and C39
- ASTM C642 (BWA)
- ASTM C1202 (RCPT)

Tests required for STADIUM ® analysis
- Migration test (C1202 modified)
- Drying test
- Pore solution extraction

Other
- Imagery analysis

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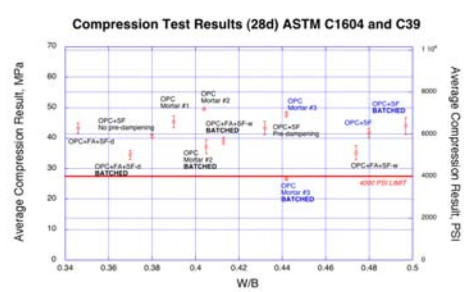
Preliminary results



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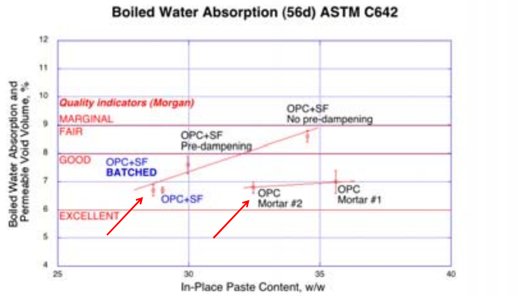
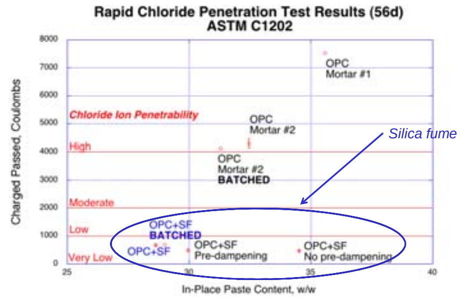
Preliminary results



Preliminary results



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Summary

- Standardized tests presented above useful for quality control
  - Relatively cheap
  - Quick results
- However, they do not allow for a reliable service life estimation
- Adapted tests are required for such an assessment
  - Migration, drying test, pore solution extraction

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Summary

- The results from this study aim at providing
  - A basis for comparison between CIP concrete and shotcrete performance
  - A better understanding of the transport properties in shotcrete
  - The groundwork for development of new shotcrete performance specifications

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Future work

- Finish experimental phase

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Future work

- Analyse shot and batched mixes using STADIUM ®
- Vary exposure conditions
  - Marine infrastructure
    - Saline environment
    - From piles to top deck
  - Road infrastructure
    - De-icer salt
- Estimate service life
  - Compare mixes from project results
  - Compare mixes from SUMMA results

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Thank you

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- CEP Forensic Engineering

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