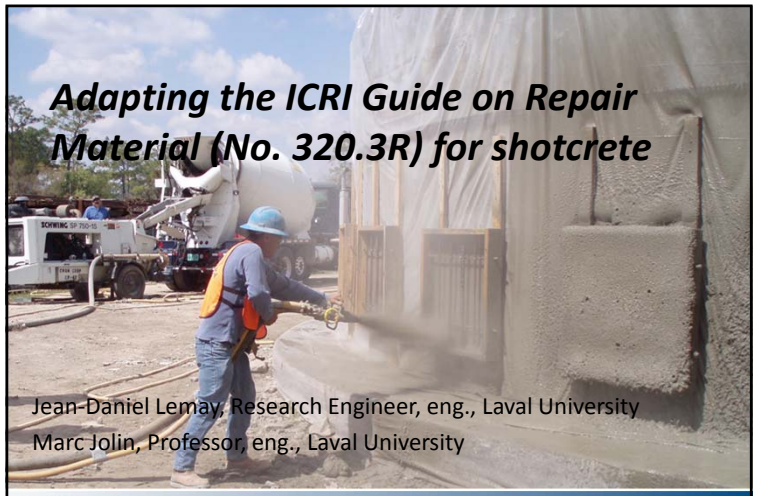

Adapting the ICRI Guide on Repair Material (No. 320.3R) for shotcrete

Jean-Daniel Lemay, Research Engineer, eng., Laval University
Marc Jolin, Professor, eng., Laval University

What is guide No. 320.3R

- 320.3R : Guideline for inorganic Repair Material Data Sheet Protocol
- Provide a common ground for all repair material

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Why this project ?

- Shotcrete, by it's unique nature, cannot be assessed correctly with guide 320.3R
- The repair industry represents an important market for shotcrete
- In 2016, a *Collaborative Research and Development* grant was awarded for Shotcrete related projects (5 years)
  - *King Shotcrete Solutions & the Natural Sciences and Engineering Research Council of Canada (NSERC)*

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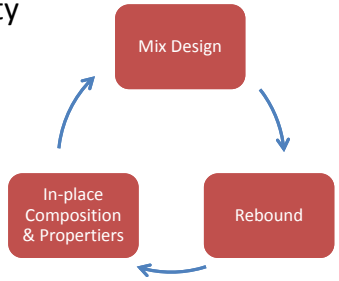
What is shotcrete ?

Misconception of Shotcrete

- Aggregate grading selection
- Importance of velocity
- Bond to substrate
- Curing
- Rebound



Testing shotcrete

- Shotcrete specimens are *(most of the time)* extracted from standard test panel*
  - Coring and sawing is inevitable !

Central section: 610 mm x 610 mm
Height : 89 mm

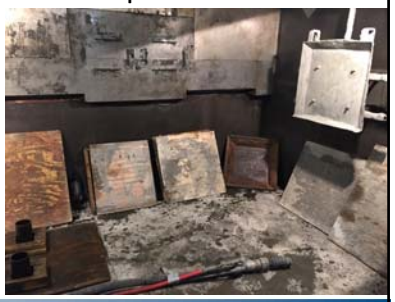
* ASTM C1140 : Preparing and Testing Specimens from Shotcrete Test Panels

Testing shotcrete

- What is usually cast in moulds must be rethink in term of rebound entrapment
- Additional step must be taken

Testing 320.3R

- Exhaustive testing program
- Require numerous panel and specific mold



Testing 320.3R

- Require a lot of testing !

- Missing
  - 1 day testing

The simple adaptation

- Same standard only coring or sawing of specimen
  - Flexural strength
  - Splitting tensile strength
  - Direct tensile strength
  - Rapid chloride ion permeability
  - Density, Absorption, and Voids
  - Modulus of elasticity
- Standard adaptation to shotcrete

Properties	Original Standard	Adaptation
Compressive Strength	ASTM C39	ASTM C1604

The simple adaptation

- Bond strength (ASTM C1583)
  - Cast substrate, spray tested mixture on top

Composite specimen after spraying and screeding

The simple adaptation

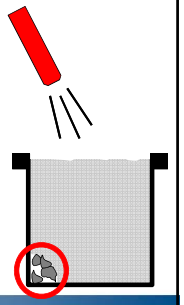
- Freeze-and-thaw & scaling & ponding
  - All these tests require square specimens
  - Spray bigger to saw to dimension
    - Facilitate specimen straightness
    - Allow any entrap rebound in the specimen to be cut away

The simple adaptation

- Curing regime
  - Once sprayed, panel cannot be moved before 24h
- Proposed adaptation
  - Once sprayed, panel cannot be moved
  - Wet burlap and tarp for the first 24h
  - Moved to 100 RH% room after

The more difficult adaptation

- Air content
- Cannot use ASTM C231 (pressure method)
- Impossible to correctly consolidate specimen
  - Entrapped rebound and overspray !



Adaptation

Use air content from ASTM C457 results (Air void system)

The more difficult adaptation

- Setting time
- ASTM C403 is impossible to do on dry-mix shotcrete
  - Impossible to sieve dry-mix shotcrete!
    - Mixture is too stiff

However, expired in 2001

Possible Adaptation

Use ASTM C1117 – Time of setting of shotcrete mixtures by penetration resistance

The more difficult adaptation

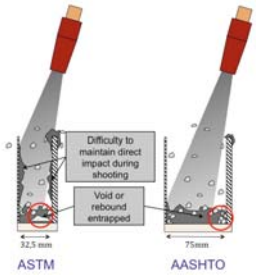
- Setting time
- Similar to C403 without the sieving

The more difficult adaptation

- Cracking resistance
- Because of the mould configuration ASTM C1581 cannot be used
- AASHTO version should be preferred

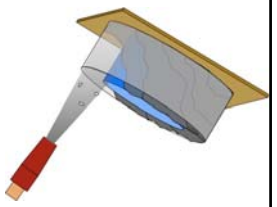
More information

Girard et al., *Measuring the cracking potential of shotcrete in restrained shrinkage conditions*,
CI Magazine, Accepted for publication



The more difficult adaptation

- Cracking resistance
- New spraying configuration
  - ❖ Quasi-overhead ❖ bench shooting ❖



The impossible adaptation

- Yield is impossible to determine with shotcrete !
  - The water is added at the nozzle depending on the situation, it will never be the same
  - Cannot consolidate in a close container
- What could be done …
  - Theoretical yield
  - Specified the approximate yield for a standard W/B ratio
  - Ex: For dry-mix shotcrete -> 0.42

The impossible adaptation

- Unit weight
- Similar problem to air content and yield
- Cannot consolidate correctly
- Literature* suggest using bulk dry density JD Lemay1 from ASTM C642 for a good approximation to fresh unit weight

*Design and control of concrete mixtures 8th Canadian Edition, Kosmatka and al., 2011

Slide 20

JD Lemay1 À confirmer je ne retrouve plus l'endroit dans le livre de dosage
Jean Daniel Lemay, 2/9/2017

What is better not done

- Creep – ASTM C512
- Why ?
  - Producing 150 mm cores
  - Not producing panel but massive chunk of concrete !
  - Around 500 kg for 1 panel !

What is better not done

- Chemical resistance – Spot Test
  - Not useful for shotcrete
  - Unnecessary for usual shotcrete application

What should be added

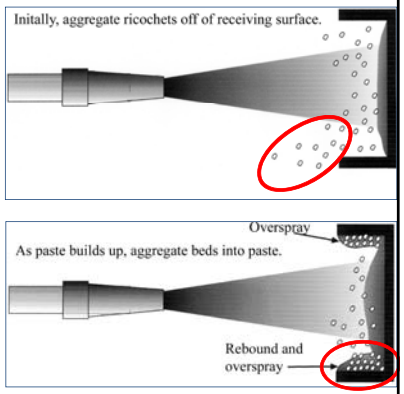
- By it's unique placement method, additional test should be added for shotcrete
  - Early age (for accelerated)
    - Ex : 4h, 6h

What should be added

- Early Age - End beam test

What should be added

- Rebound
  - What is rebound ?
  - Entrapment problems



What should be added

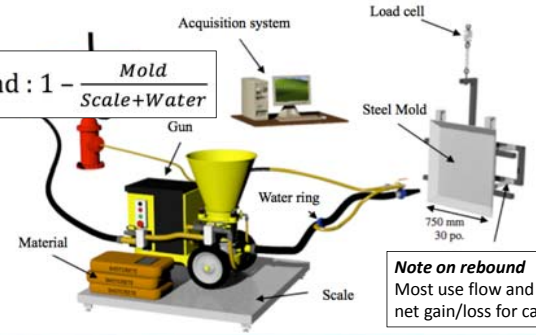
- Rebound
  - Very important from an economical point of view
    - Lower rebound mixture might cost more but ….
      - Lower labour needed
      - Lower waste
      - Lower environmental impacts
      - Etc.
  - Primordial information for any shotcrete mixture !

What should be added

- Rebound

How it is determined in the lab?

$$\text{Rebound} : 1 - \frac{Mold}{Scale+Water}$$

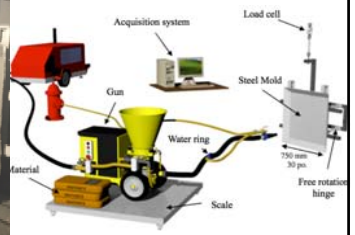


Note on rebound
Most use flow and not mass net gain/loss for calculation

What should be added

- Rebound

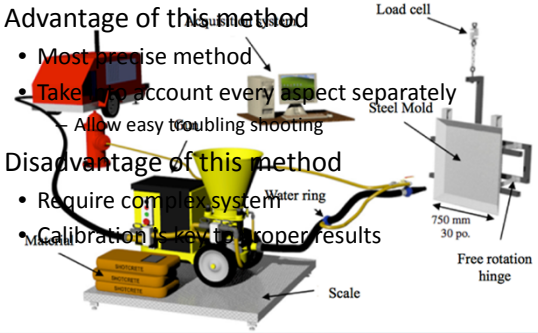
How it is determined in the lab?



What should be added

How it is determined in the lab?

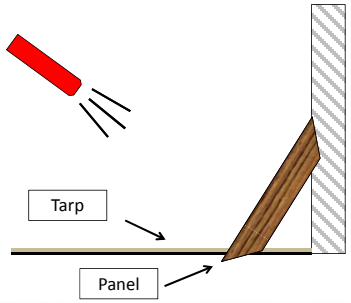
- Rebound
  - Advantage of this method
    - Most precise method
    - Takes into account every aspect separately
    - Allow easy troubling shooting
  - Disadvantage of this method
    - Require complex system
    - Calibration is key to proper results



What should be added

How it can be determined in the field?

- Rebound



The tarp and mold method

$$\text{Rebound} : 1 - \frac{Mold_{\Delta\ mass}}{Mold_{\Delta\ mass} + Tarp_{\Delta\ mass}}$$

What should be added

How it can be determined in the field?

- Rebound
  - Advantage of this method
    - Does not require elaborate equipment
  - Disadvantage of this method
    - Reliability of the results
    - Nozzleman technique influence results

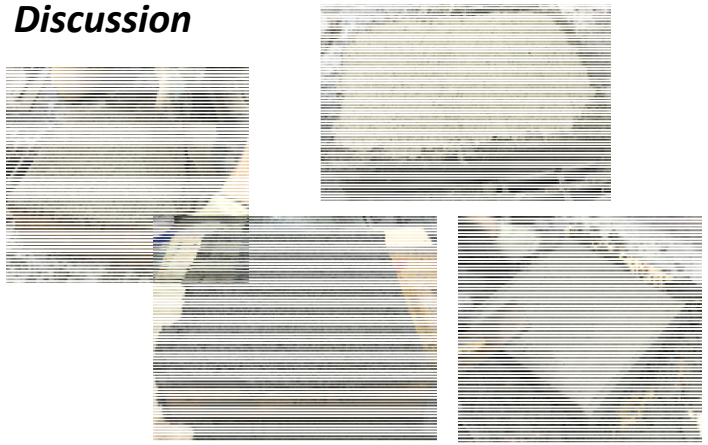
Discussion

- Additional care must be taken with accelerated mixture
  - Setting of shotcrete is WAY faster than cast in-place
    - Finishing time can be less than 1 minutes
  - Extra care must be taken for surface sensitive tests
    - Bond strength
    - Freeze-and-thaw
    - Scaling
    - Chloride ponding

Discussion

- Surface must be carefully prepared
  - An “aggressive” trowelling will create cracks and invalidate the tests
  - A “passive” trowelling will leave a bumpy surface often resulting in low durability results

Discussion



Recommendation

- Need an experimented team
  - Specially for accelerated dry-mix!
- Add the rebound test to the specification
- Take special care for surface finish
- Always think rebound entrapment!!!
  - This dictate most of the required change!!!

Recommendation

- The guide should either :
  - Generalize the proposed standard to include shotcrete
  - Add a specific point / note to confirm that additional step or action must be taken when testing shotcrete

Conclusion

- Testing shotcrete via Guide 320.3R is possible !
  - Shotcrete is a unique placement technique
  - It is possible to follow guide 320.3R
    - However … rebound and overspray must be controled
    - All the testing program must be thought in function of placement particuliarity
- It is possible to provide scientifically valid results by guide 320.3R for shotcrete !!!

Acknowledgement

- We would like to thank *King Shotcrete Solutions* for their financial and technical support in this study.

- Thank you / Merci
- Any questions?

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