Paramètres influençant l’adhérence des produits de réparation

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Paramètres affectant la qualité de la réparation *(Silfwerbrand, 2004)*

- Concrete properties
- Removal deteriorated concrete
- Cleaning after removal
- Surface properties
- Surface preparation
- Bonding agents
- Mechanical devices across the interface
- Concrete placement
- Concrete curing
- Time dependance
- Traffic, ..

Facteurs prédominants

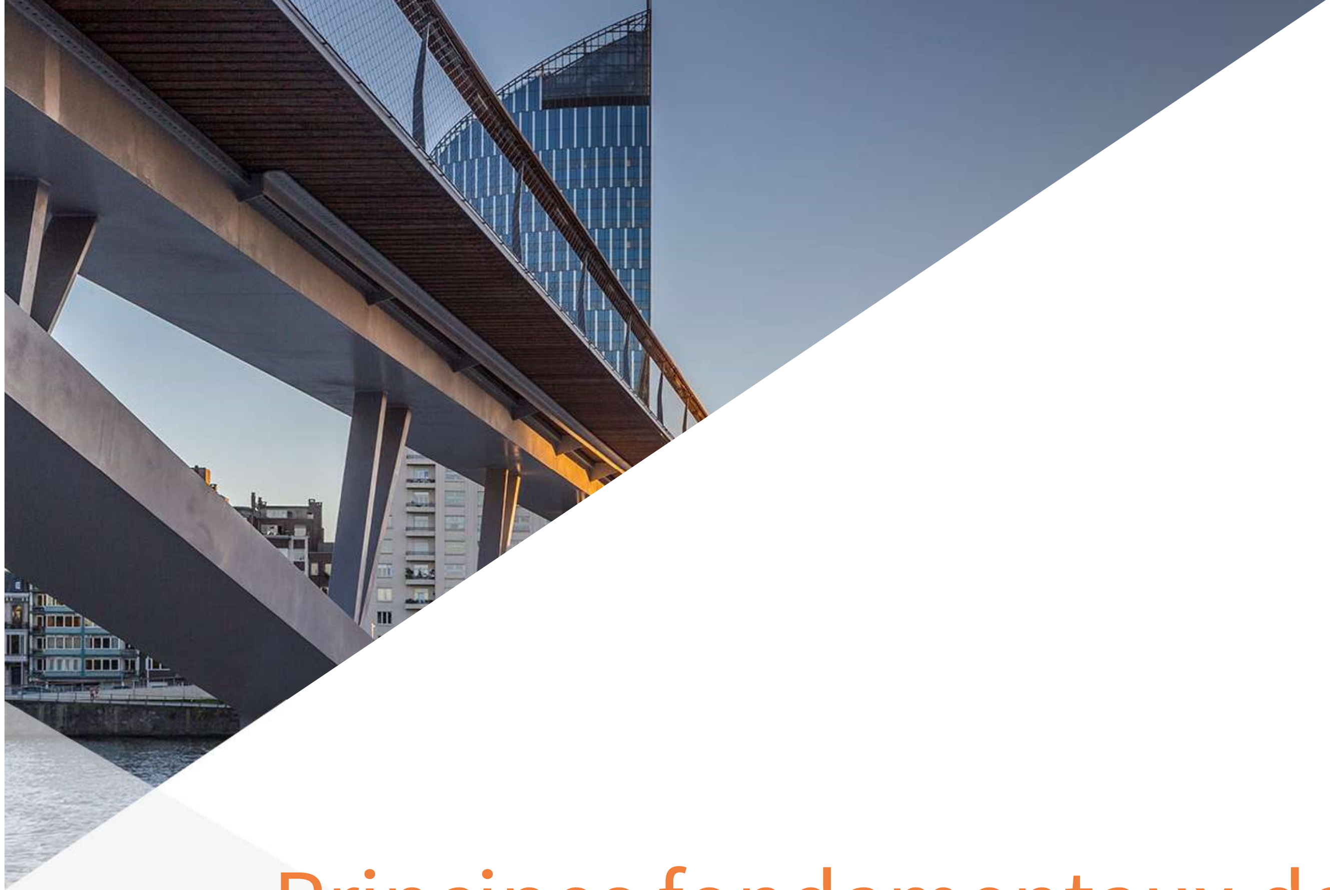
Méthode de préparation du béton support

Absence de laitance

Propreté avant placement de la réparation

Compaction du produit de réparation

Cure du produit de réparation



LIÈGE université
Sciences Appliquées

Principes fondamentaux de l’adhérence

UEE
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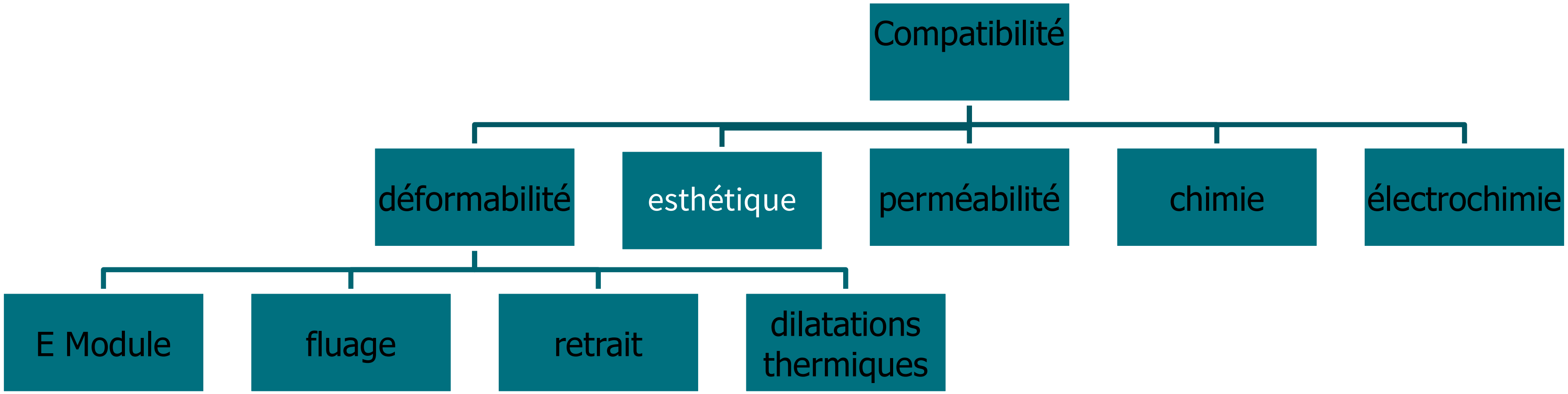
Compatibilité = … adhésion

- 3 éléments: support, matériau de réparation, environnement



Patch repair: compatibility issues. A. Garbacz, L. Courard, B. Bissonnette, W.Głodkowska. 5th International Conference on Concrete Repair, Queen's University, Belfast, 1-3 September 2014, 71-76.

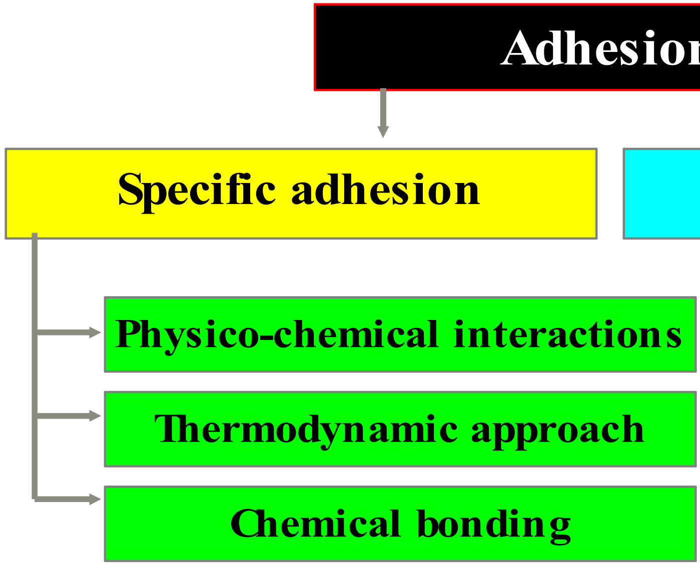
Compatibilité = … adhésion
(Deryagin, 1973)

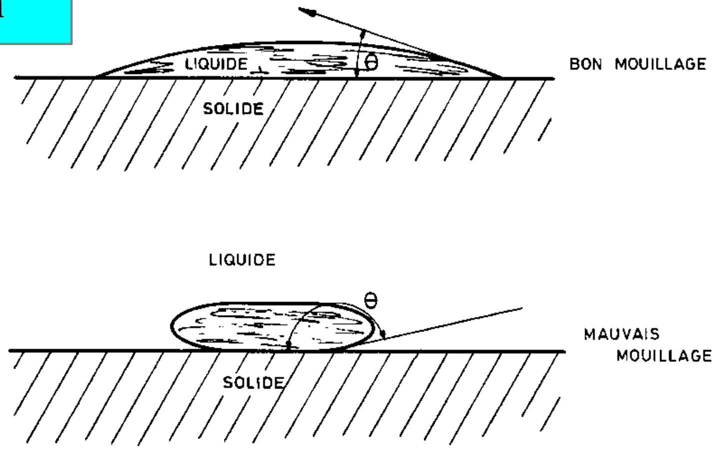
- processus par lequel deux corps sont mis en contact et attachés (liés) l'un à l'autre
- processus de séparation (rupture) d'un lien entre deux corps qui étaient en contact

⇒ **conditions et cinétique de contact**

⇒ **processus de séparation**

Compatibilité = … adhésion



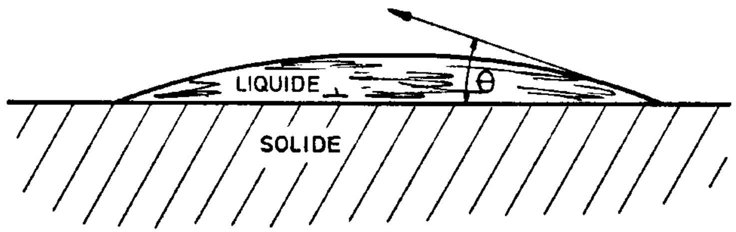


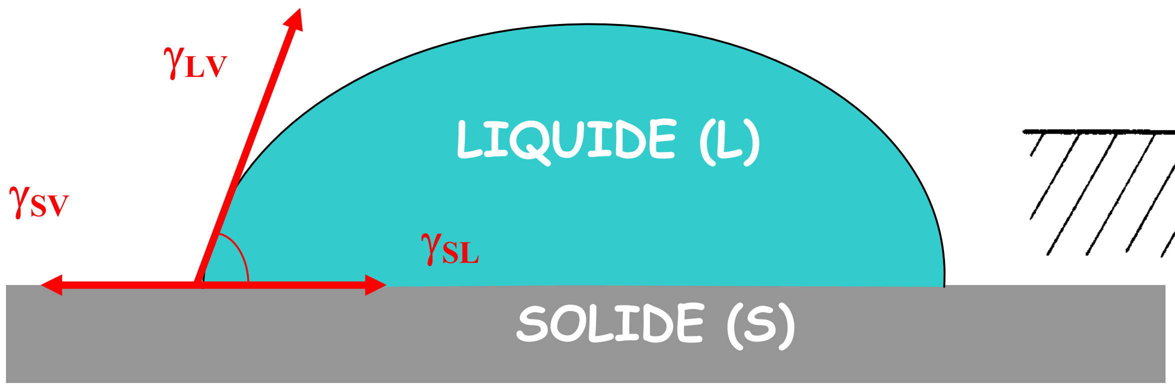
Condition 1 : étalement et mouillabilité

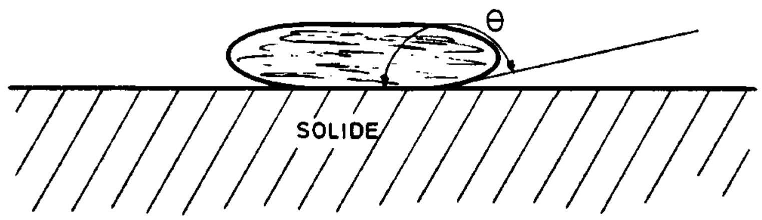
Condition 2 : interactions physico-chimiques

Condition 3 : interpénétration mécanique

Condition 1 : étalement





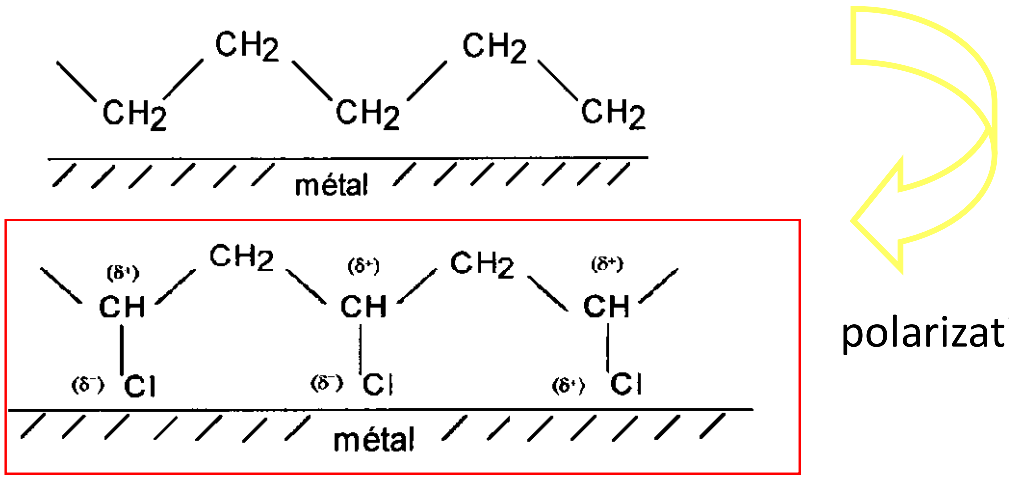


$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \cos\theta$$

Meilleure mouillabilité du solide par le liquide si l'angle de contact est PETIT

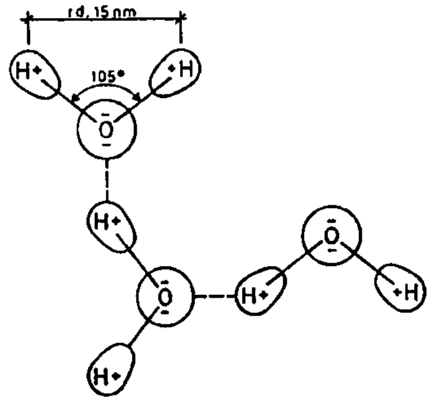
Condition 2 : interactions physico-chimiques

Van der Waals

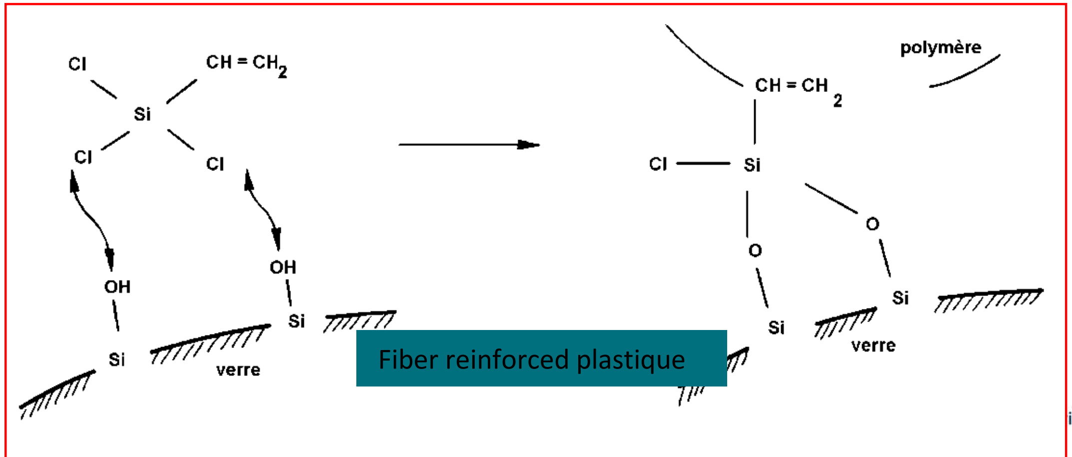


polarization

Pont hydrogène

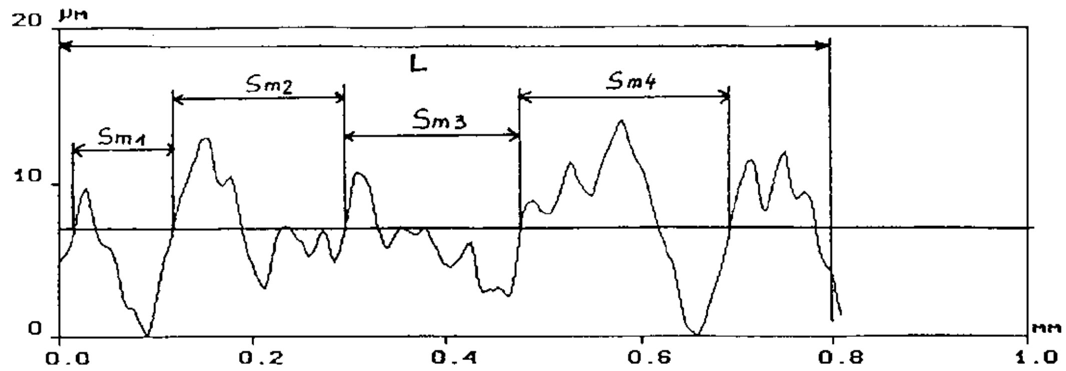


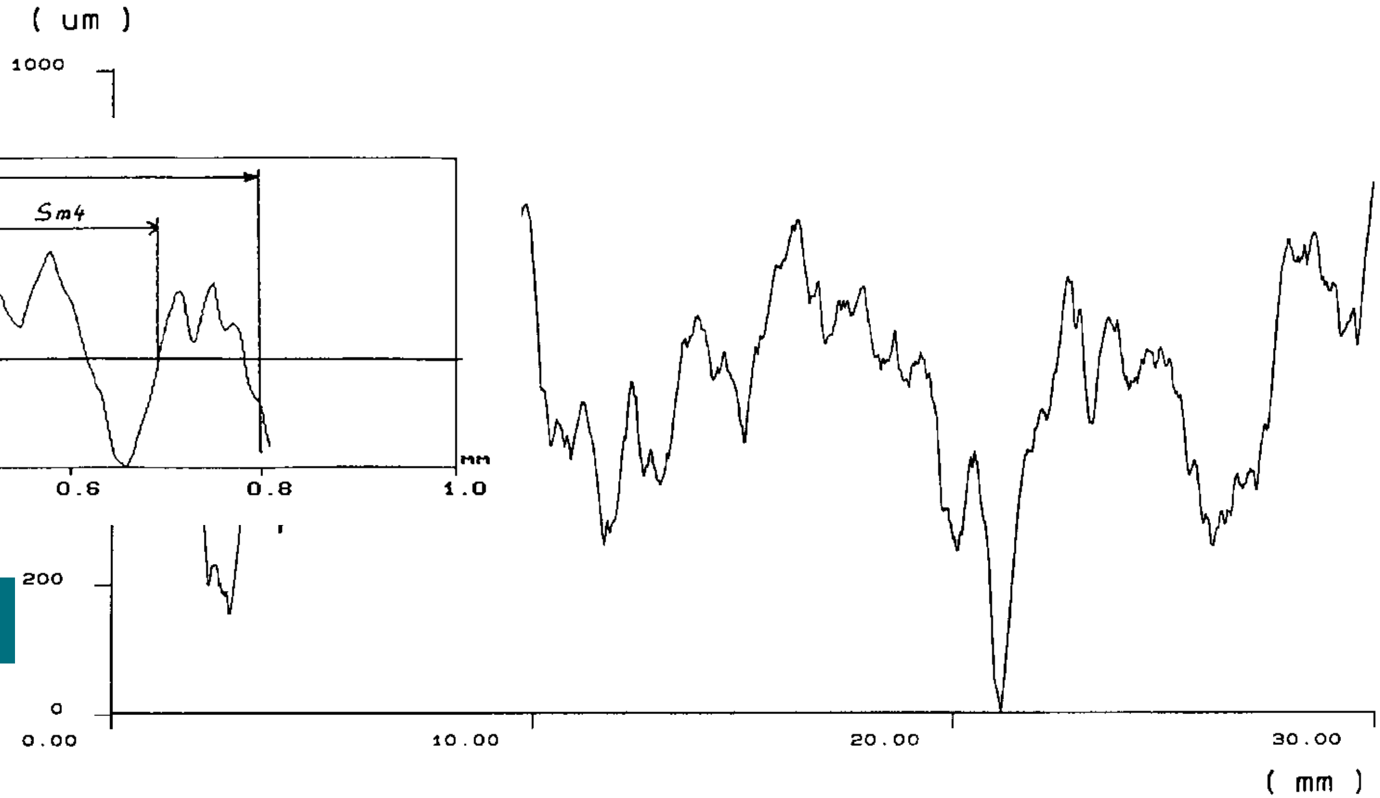
Liaisons chimiques



Fiber reinforced plastique

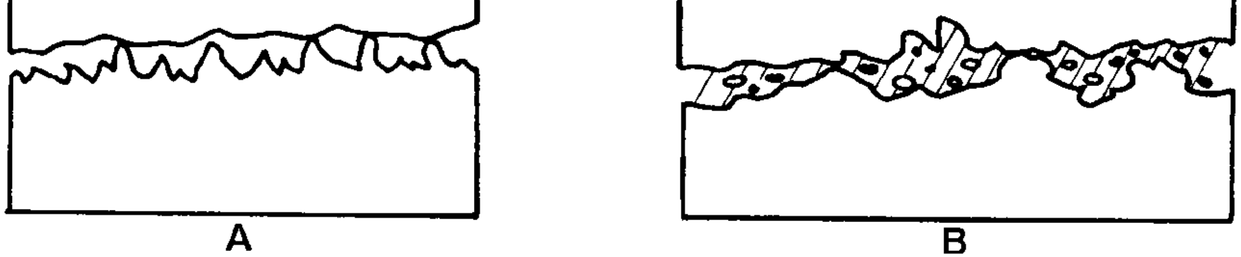
Condition 3 : interpénétration mécanique





Définition du profil

efficacité?



CONCRETE REPAIR BOND :

EVALUATION & FACTORS OF INFLUENCE

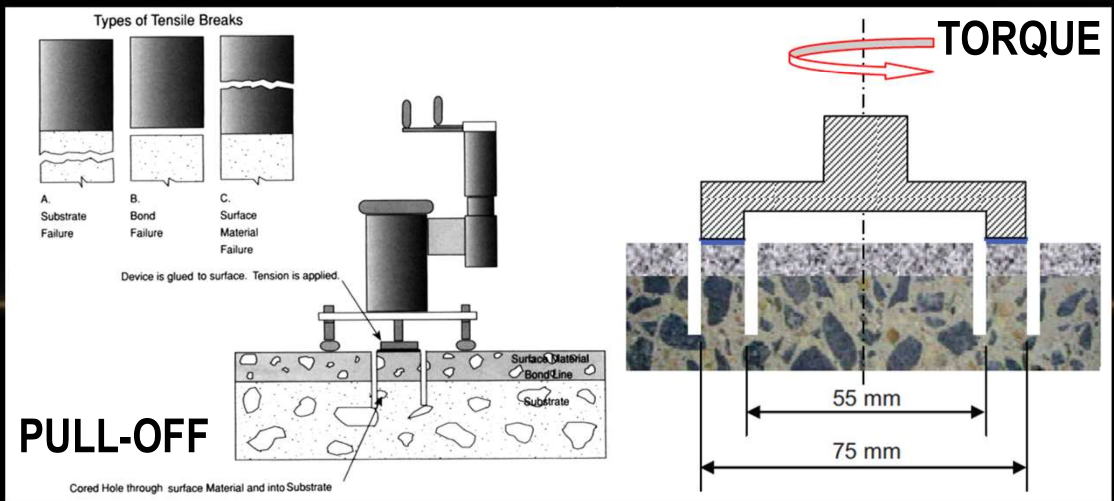
B. Bissonnette — Laval University, Canada
L. Courard — University of Liège, Belgium
A. Garbacz — Warsaw University of Technology, Poland
A.M. Vaysburd — Vaycon Consulting, USA
K.F. von Fay — US Bureau of Reclamation, USA

OBJECTIVES

- Concrete repair bond evaluation
  - To evaluate the effect of load misalignment upon tensile pull-off test results
  - To evaluate the correlation between tensile/shear bond strength and surface roughness
  - To evaluate the optimum moisture conditioning of a concrete substrate prior to repair
  - To evaluate the effect of substrate carbonation upon repair bond strength

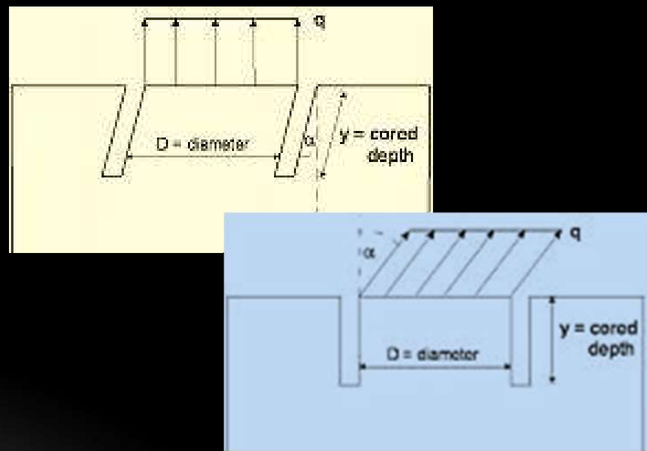
GENERAL TEST PROGRAM

- Test specimens
  - Support slabs cast, conditioned, profiled and repaired
- Repaired slab testing
  - Pull-off testing for tensile bond strength (ASTM C1583; EN 1542:1999)
  - Torque testing for torsional (shear) bond strength



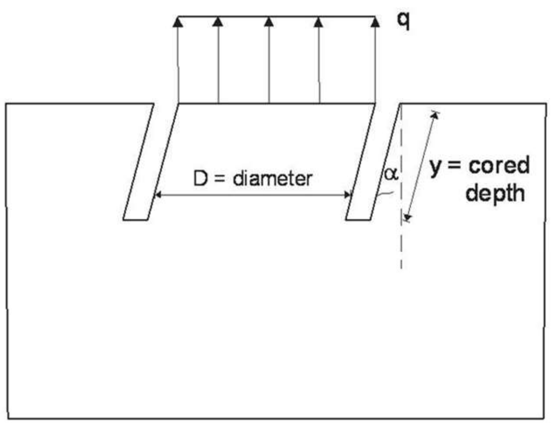
METHODOLOGY

- Influence of pull-off test misalignment
  - Test program
    - Series of 600×400×100 mm test slabs (6) prepared with three different concrete mixtures (30 MPa; 40 MPa; 50 MPa)
    - Controlled coring misalignment
      - core inclination: 0°; 2°; 4°
      - coring depth: 15 mm; 30 mm
  - Complementary FEM analysis (elastic) analysis
    - Source of misalignment: coring *vs*. load
    - No significant difference

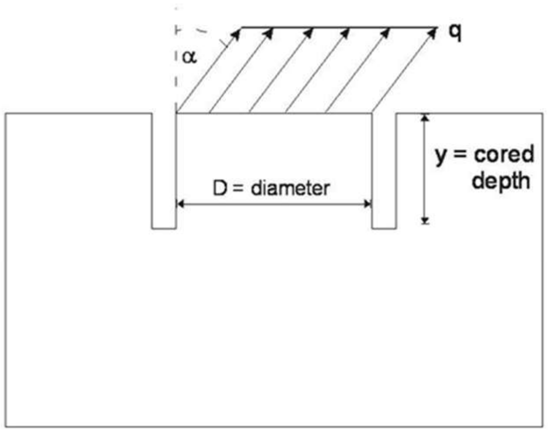


Expertises in situ – résistance

- Essai d’arrachement / adhérence (…)



a) Core axis inclination

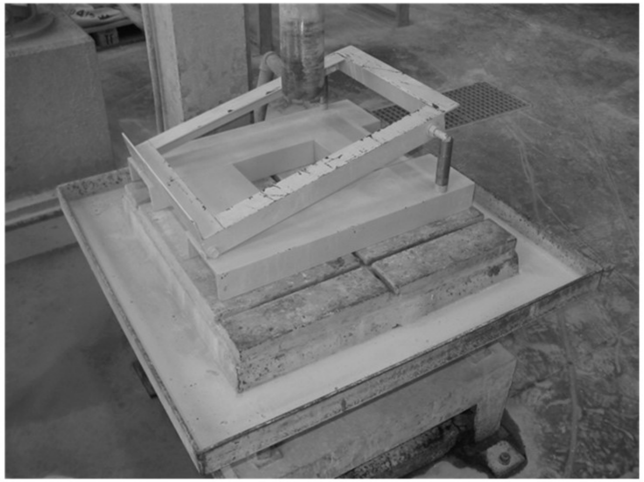


b) Load inclination

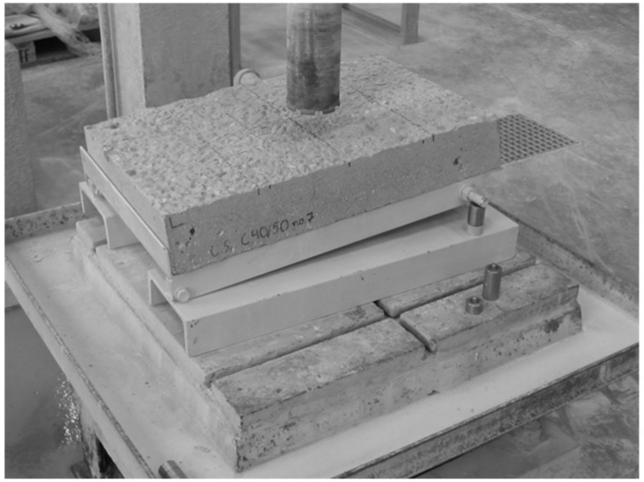
Effect of misalignment on pull-off test results: numerical and experimental assessments. L. Courard, B. Bissonnette, A. Garbacz, A. Vaysburd, K. von Fay, G. Moczulski, M. Morency. ACI Materials Journal, 111 (2), 2014, 153-162 (http://hdl.handle.net/2268/164477).

Expertises in situ – résistance

- Essai d'arrachement / adhérence (…)

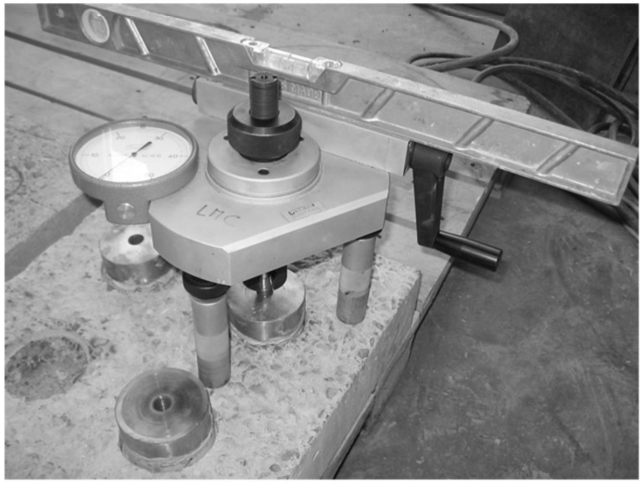


a) Special device for controlling the coring axis inclination



b) Slab positioning for coring at an angle of 4°

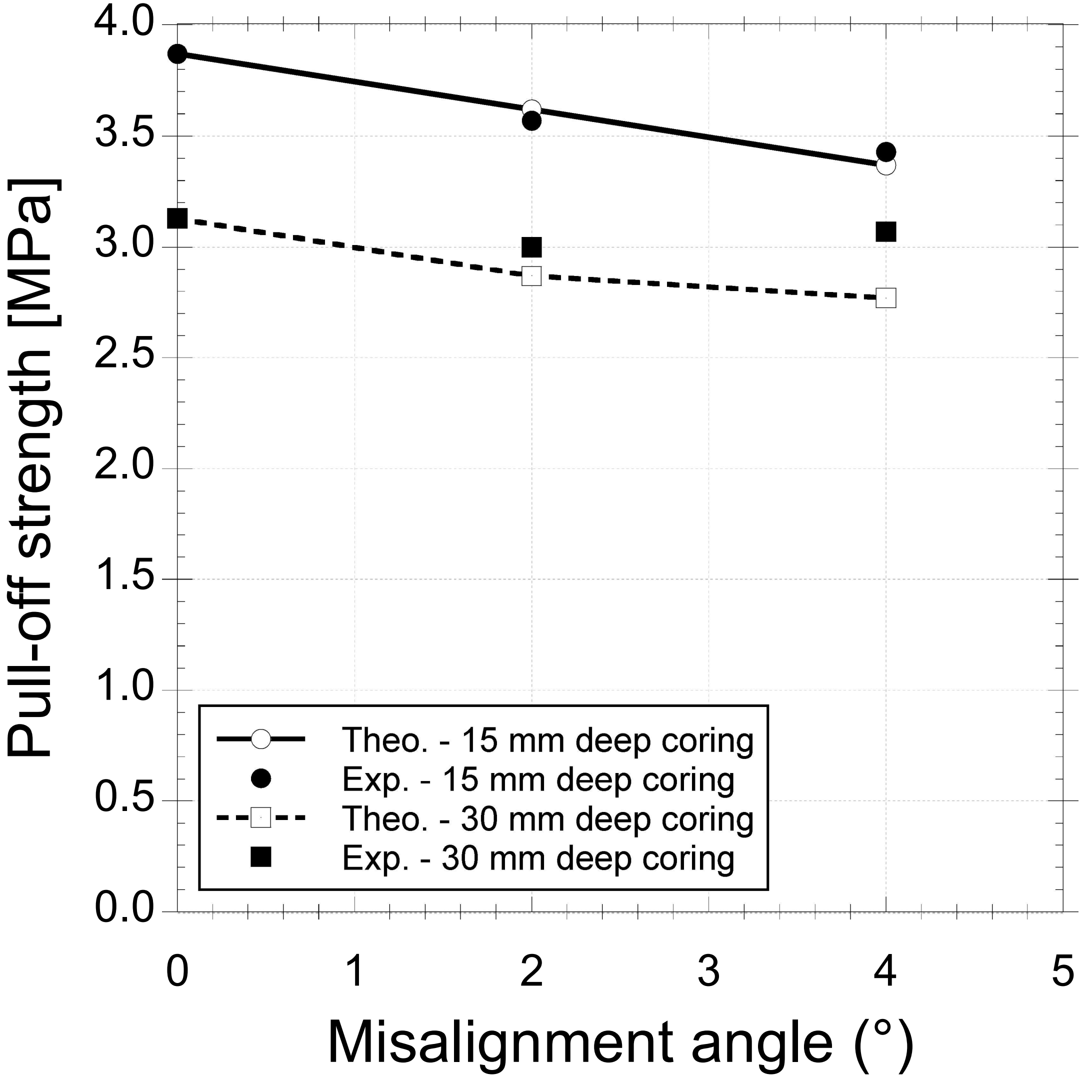
c) Dolly installation



d) Positioning of the pull-off test device

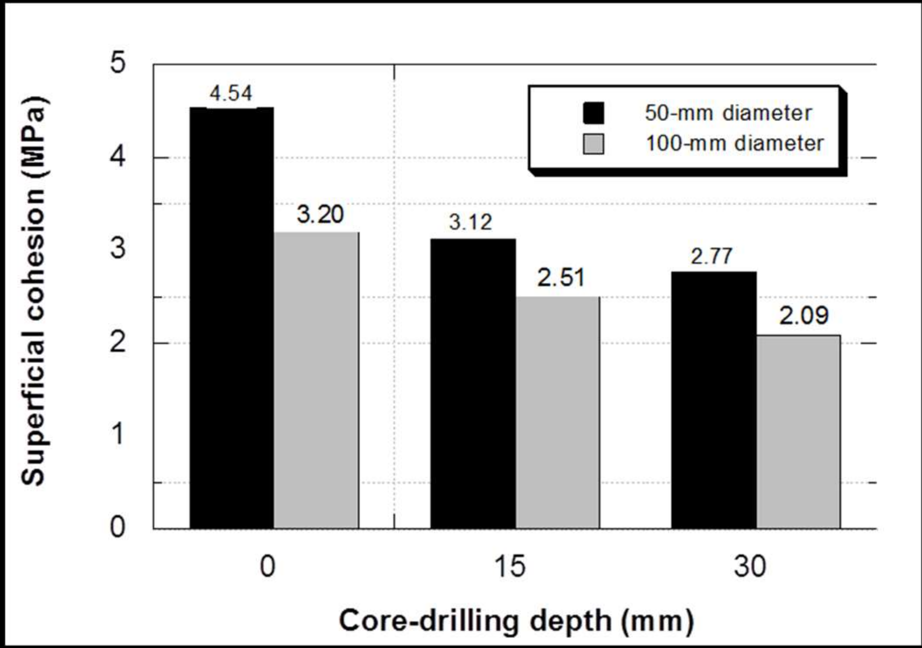
Expertises in situ – résistance

- Essai d'arrachement / adhérence (…)



PULL-OFF TEST

- Used for evaluating the *cohesion* of a reference concrete surface
- Parameters
  - metal disk thickness and diameter
  - core drilling depth
  - loading rate (<0,05 MPa/s)
  - adhesive type and thickness
  - number of tests



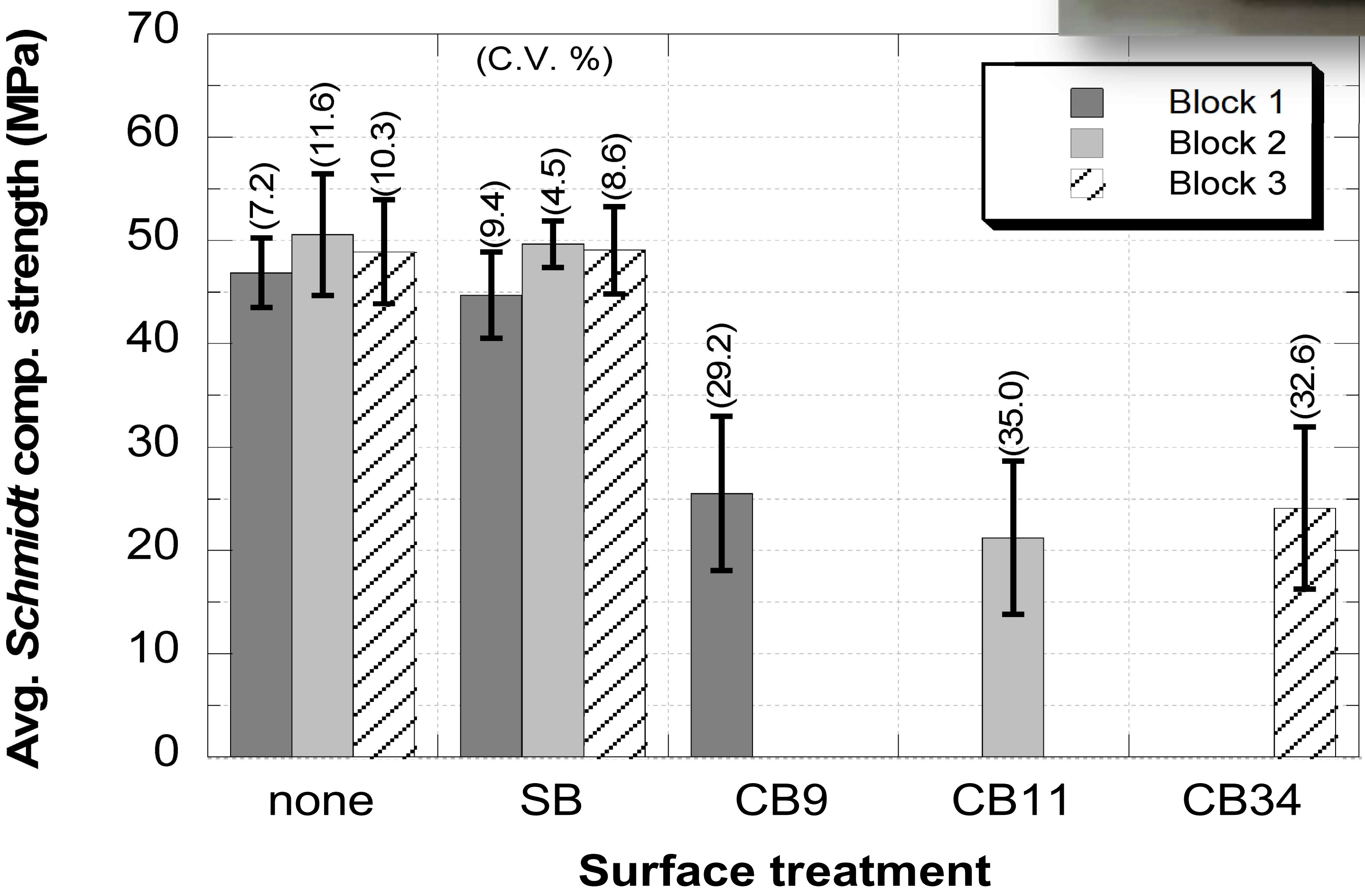
- A statistical result analysis revealed that *disk diameter* and *core-drilling depth* are the most significant parameters

Bissonnette et Courard [2004]

Effect of surface preparation

- The *Schmidt* rebound hammer results obtained for the surfaces prepared with *concrete breakers* exhibit much more variability
  - variability in the procedure (applied force, duration)
  - angle between the axis of the hammer and the concrete surface
  - surface topology (the hammer tip can hit an aggregate, cement paste or both)

Expertises in situ – résistance



Average compressive strength values estimated from the Schmidt rebound hammer tests on slab specimens after different surface treatments (SB: sandblasting; CB9: 9-kg concrete breaker; CB11: 11-kg concrete breaker; CB34: 34-kg concrete breaker)

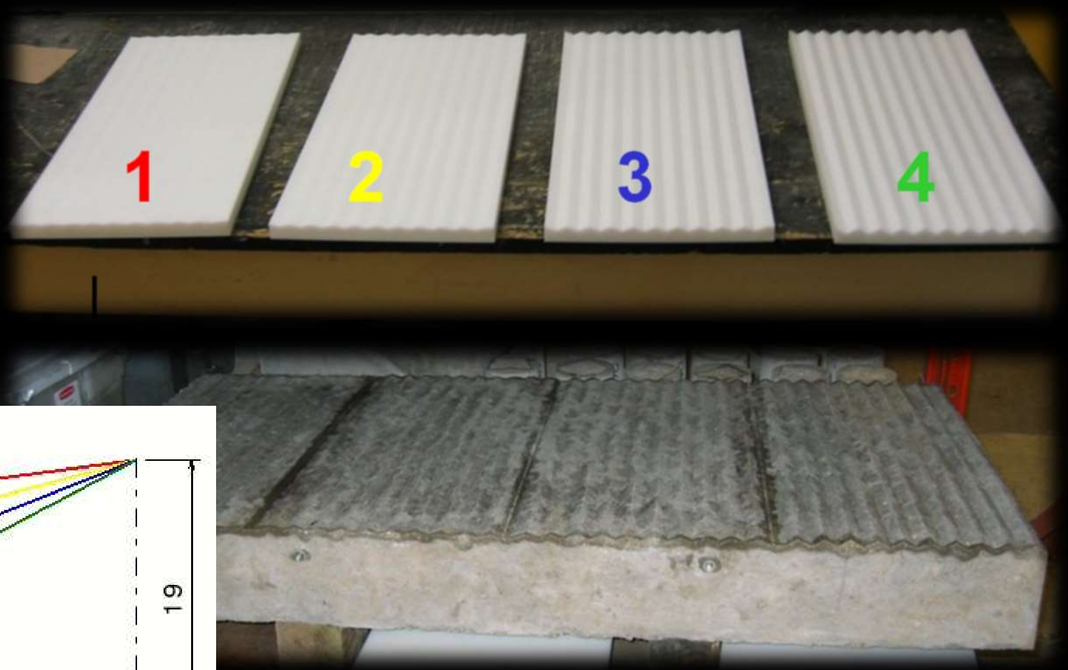
Comparison of destructive methods to appraise the mechanical integrity of a concrete surface. L. Courard, B. Bissonnette, A. Vaysburd, N. Belair and F. Lebeau. Concrete Repair Bulletin 25(4) (July-August 2012), 22-30 (http://orbi.ulg.ac.be/handle/2268/113342).

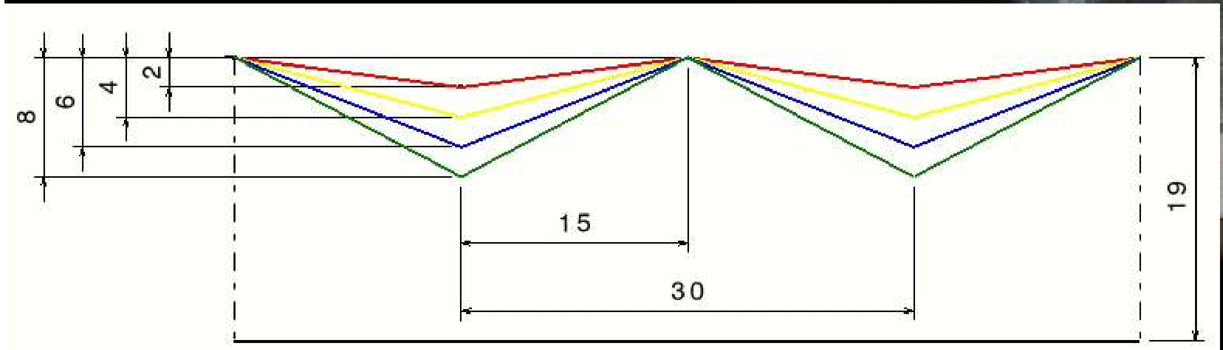
METHODOLOGY

- Influence of surface preparation
  - Series of 650×1250×150 mm test slabs (15) prepared with two different concrete mixtures (25 MPa; 35 MPa)
    - Slabs overlaid with OPC concrete after moisture stabilization and surface preparation
  - Investigated techniques
    - Sandblasting (SaB)
    - Shotblasting (ShB)
    - Scarifying (Sc)
    - Hydrojetting 100-MPa (HJ)
    - Jackhammering 7-kg (JH)

METHODOLOGY

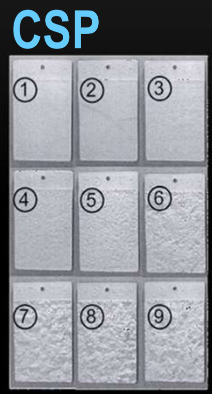
- Influence of surface preparation
  - Reference: artificially-profiled slab
    - No damage induced by the profiling operations
  - V-shape rippled acrylic dies installed at the bottom of the slab (λ = 30 mm)
    - A = 2 mm
    - A = 4 mm
    - A = 6 mm
    - A = 8 mm

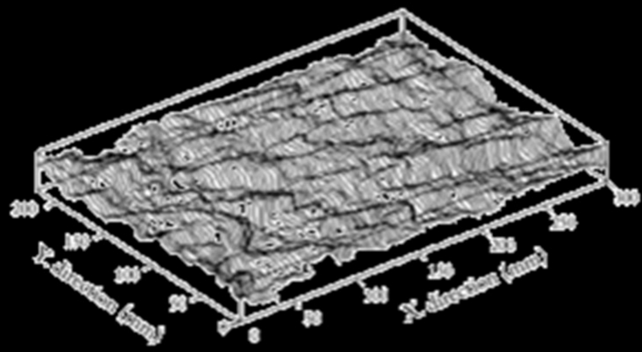




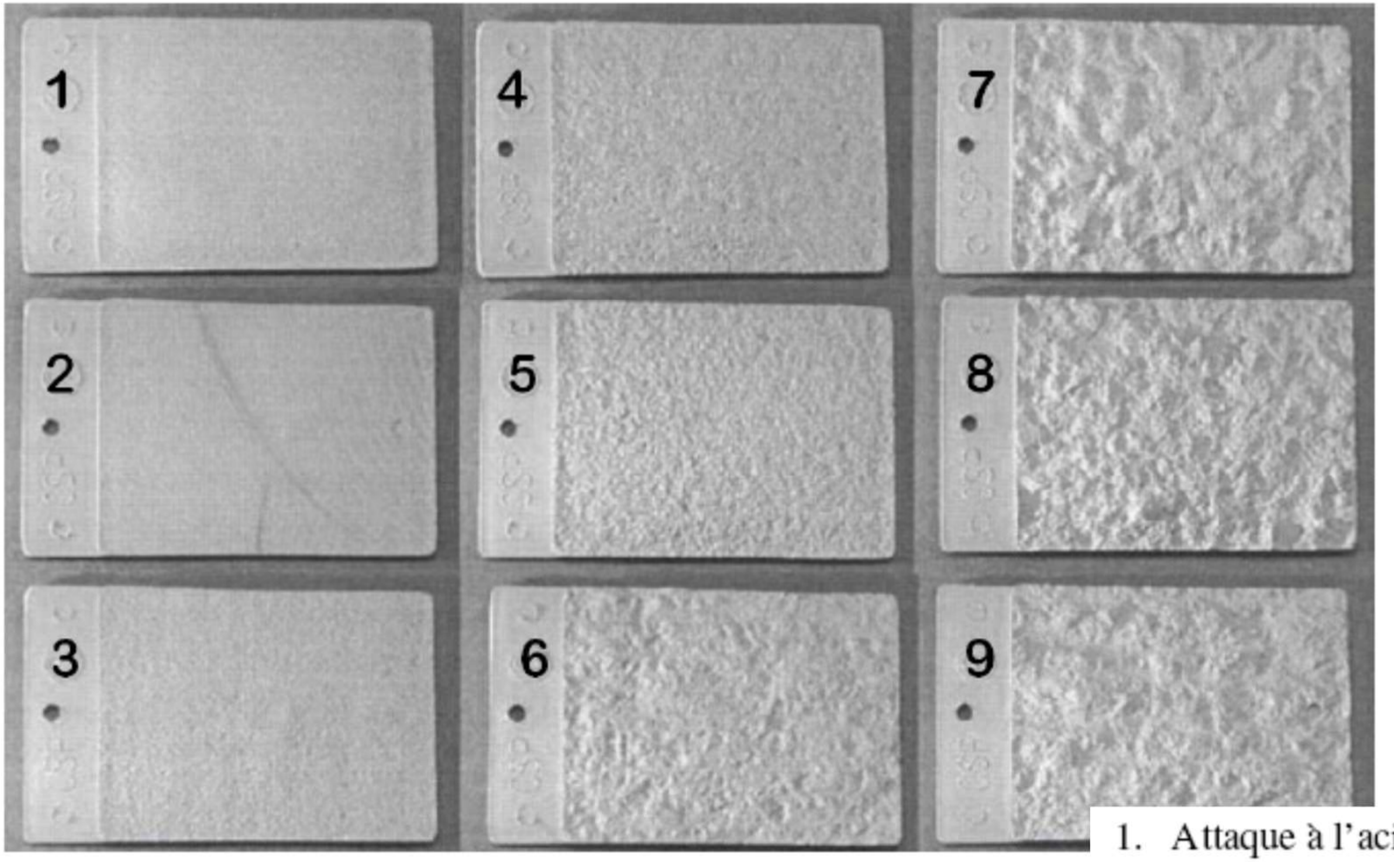
METHODOLOGY

- Influence of surface preparation
  - Roughness
    - CSP (*concrete surface profile*) index: 1 - 9 (ICRI Guideline No. 03732 / molded replicas)
    - *Sand patch* test (ASTM E965; EN 13036-1:2002)
    - Optical profilometry (*Moiré*-type)
  - Mechanical integrity
    - Pull-off experiments (superficial strength)
    - *Schmidt* hammer soundings





Méthodes de mesure: ICRI



Plaques de référence pour comparaison avec rugosité obtenue sur site

1. Attaque à l'acide
2. Meulage
3. Sablage léger
4. Scarification légère
5. Sablage moyen
6. Scarification moyenne
7. Sablage abrasif important
8. Préparation par marteau pneumatique à aiguilles
9. Scarification importante

Méthodes de mesure: tache de sable

MTD (EN 1766) = $4V/\pi D^2$ ou SRI = $(V/d^2).1272$ (sable siliceux 100/50µm)

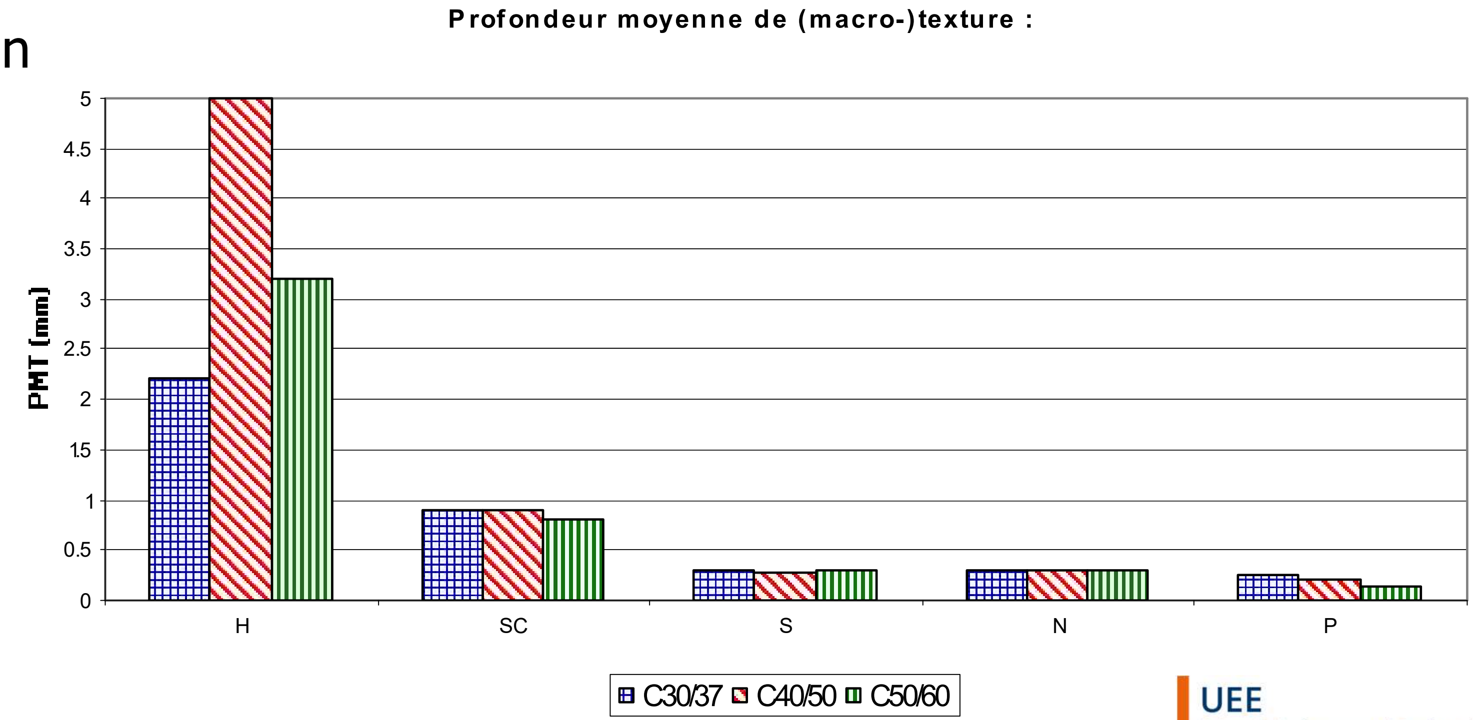
validity (from 0.25 to 5mm)

H = hydro-démolition

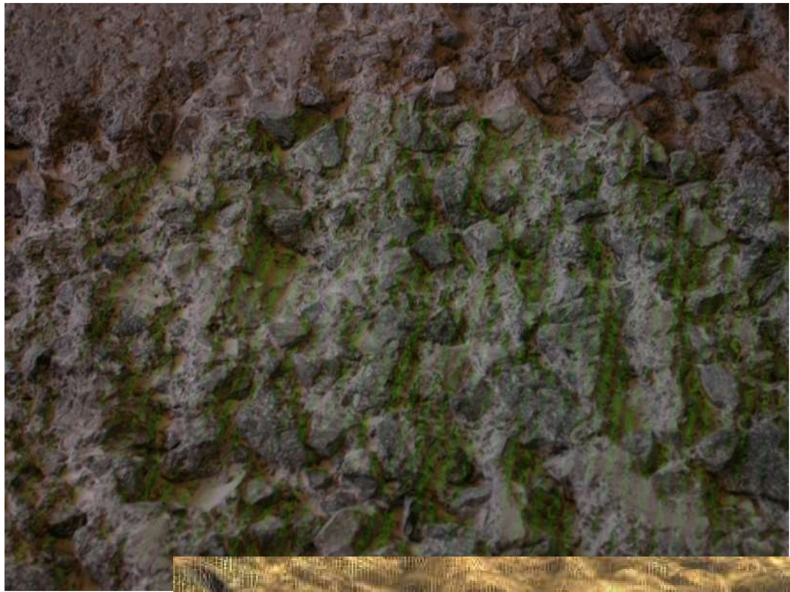
SC = scarification

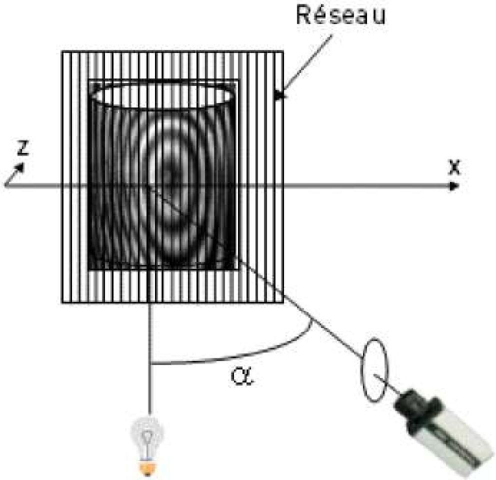
S = sablage

P = polissage

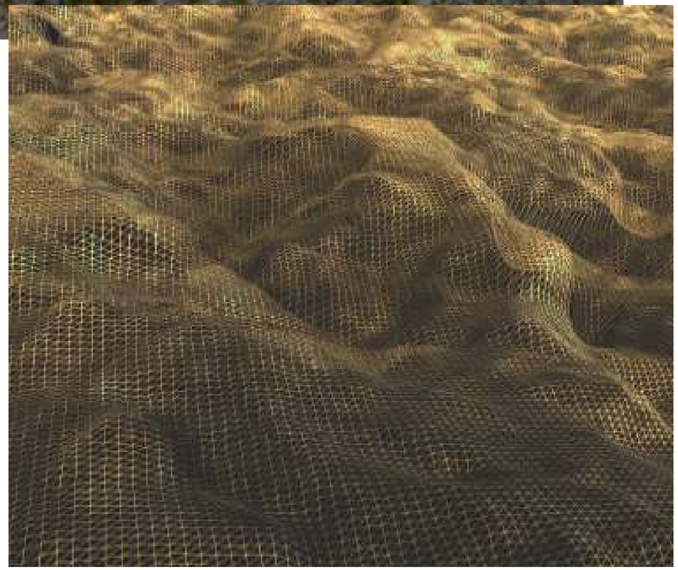


Méthodes de mesure: évaluation





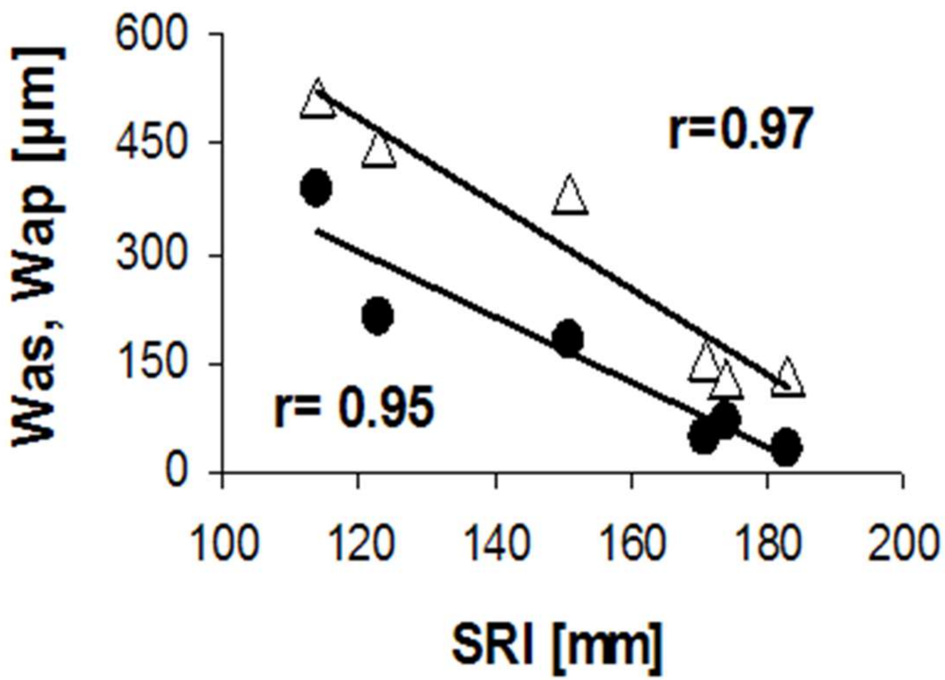
Mathematical treatment



Combination of mechanical and optical profilometry techniques for concrete surface roughness characterization. F. Perez, B. Bissonnette and L. Courard. Mag. Concrete Res, 61(6) 2009, 389-400.

Méthodes de mesure: évaluation

- Surface Rough Index vs moyenne arithmétique de l'ondulation pour profilométrie mécanique et laser (Garbacz *et al.*, 2006)



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  - Mechanical integrity
    - Pull-off experiments (superficial strength)
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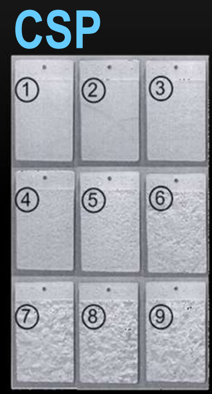
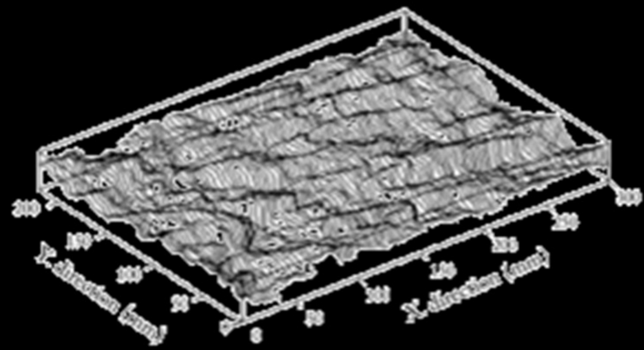
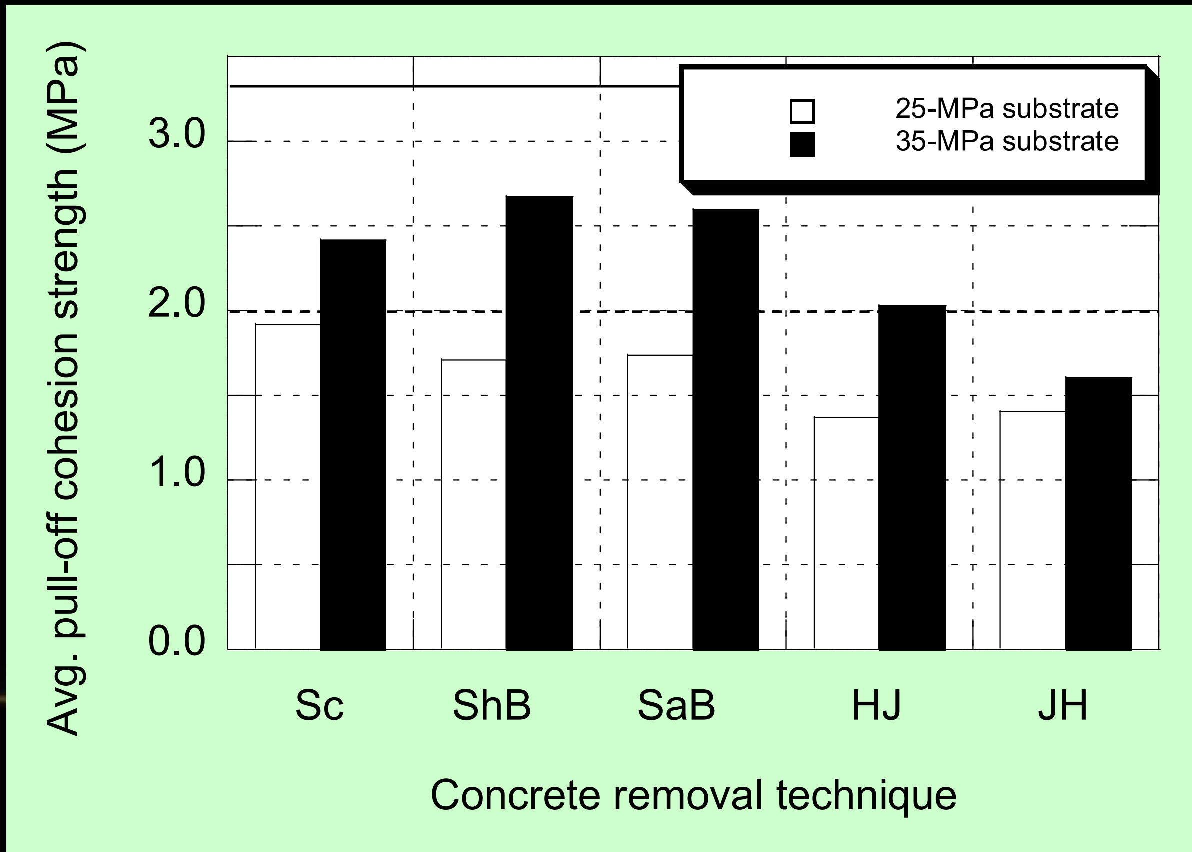
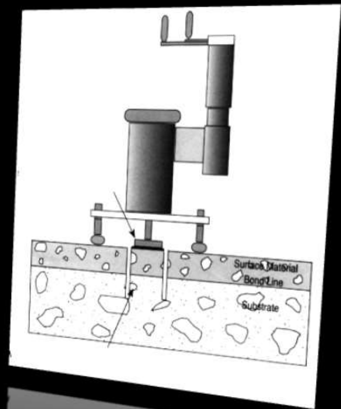




RESULTS & ANALYSIS

- Influence of surface preparation : mechanical integrity
  - Pull-off testing (superficial strength)





RESULTS & ANALYSIS

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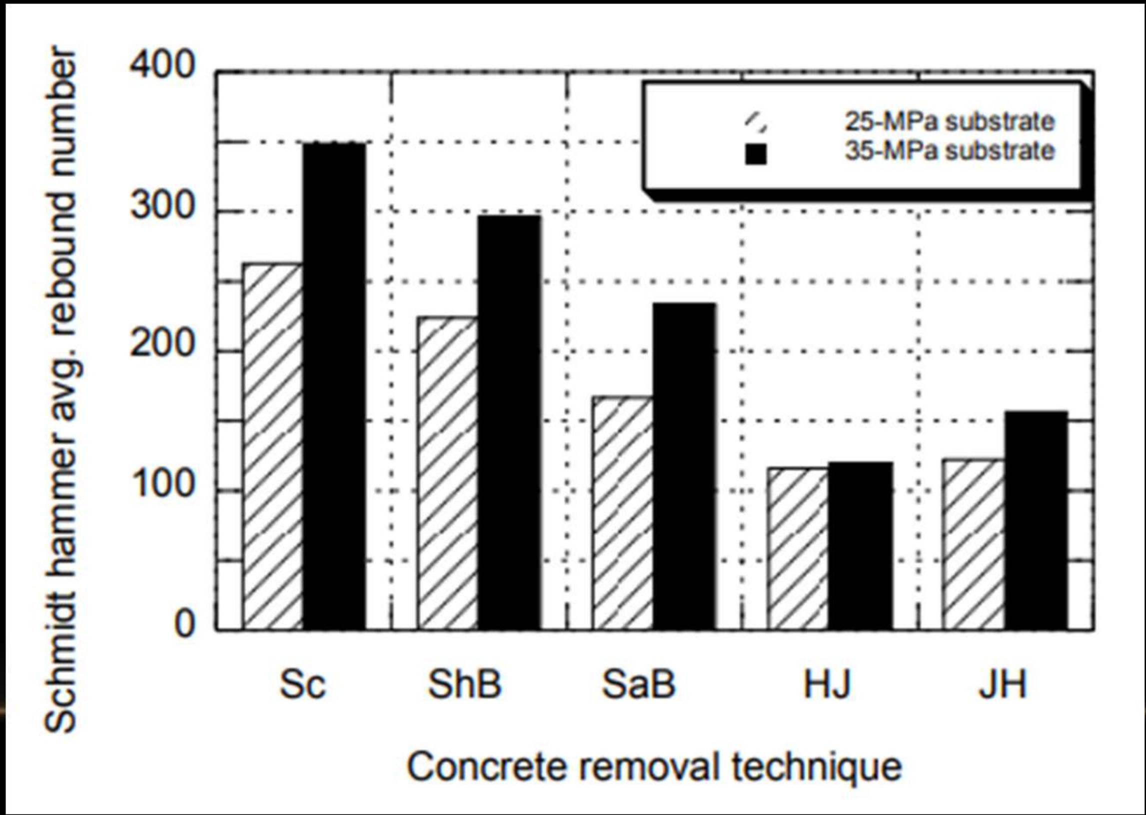
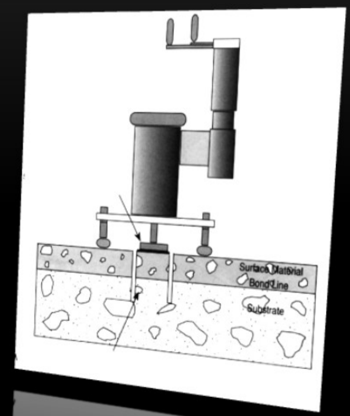
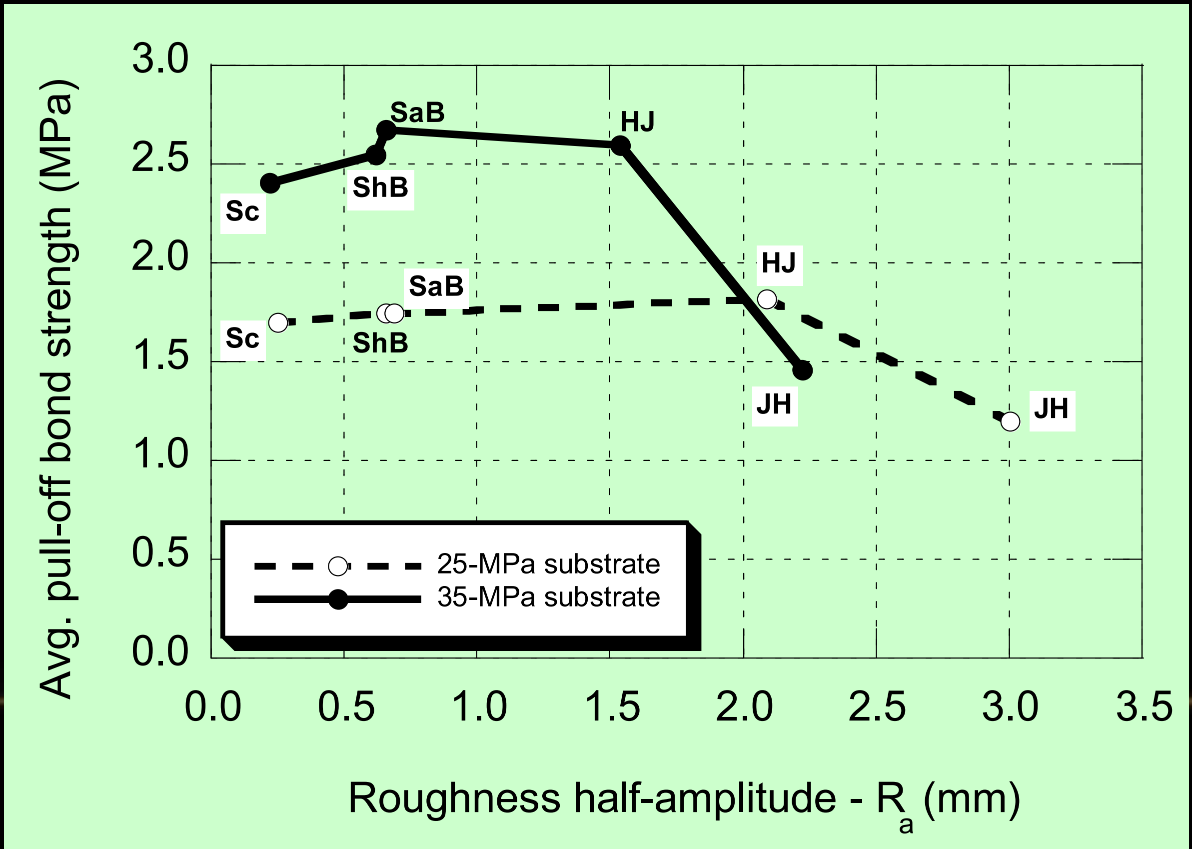


RESULTS & ANALYSIS

- Evaluation of bond strength
  - Pull-off testing (tensile bond strength)





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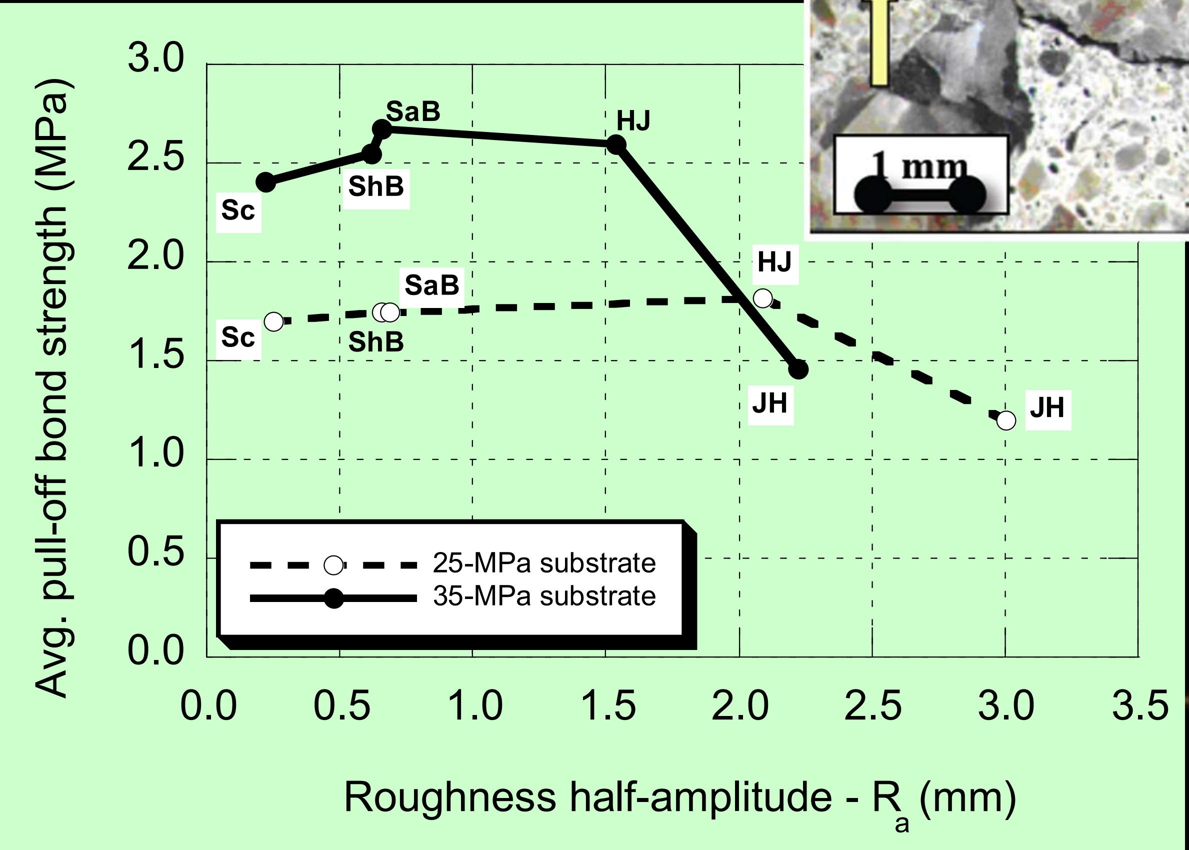
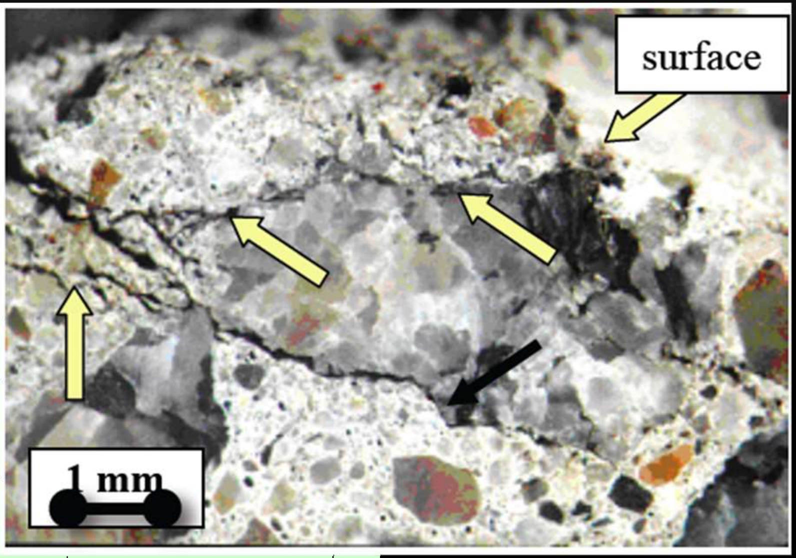
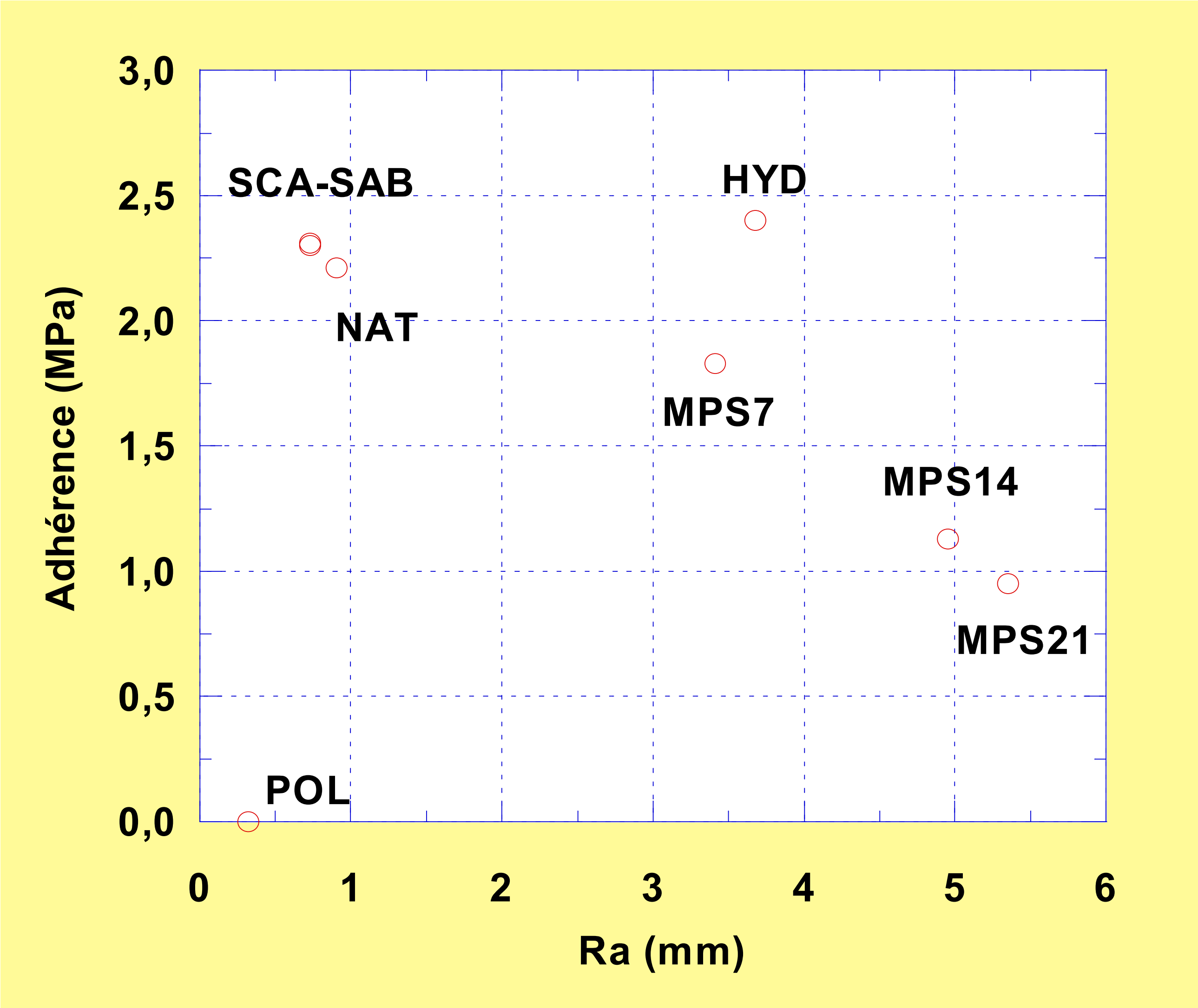




Cohésion superficielle *vs* rugosité



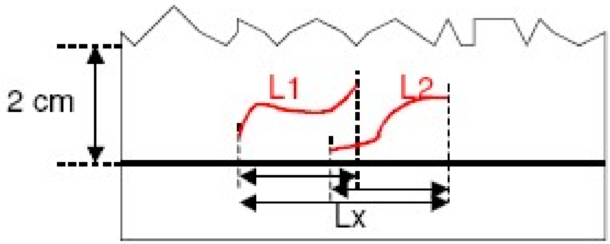
Concrete removal techniques: influence on residual cracking and bond strength. B. Bissonnette, L. Courard, A. Vaysburd and N. Bélair. Concrete International, 28(12) 2006, 49-55

Influence du type de préparation

- La cohésion du substrat est similaire pour les blocs *naturel, poli, sablé et scarifié*
- La cohésion du substrat et l'adhérence de la réparation est faible pour les marteaux pneumatiques de 14 et 21 kg
- Le polissage n'a offert aucune adhérence
- L'hydrodémolition semble être la préparation de surface qui a conduit à la meilleure adhérence
- Le sablage et la scarification donnent également une bonne adhérence et les résultats varient peu
- La rugosité n'est pas proportionnelle à l'adhérence mesurée en arrachement/traction à cette échelle

Préparation des surfaces
Prélèvements

Préparation des surfaces
Observation au microscope



(Schwall, Piotrowski)

Préparation des surfaces
Observation au microscope

Microscope binoculaire (grossissement 6 à 31x)

Demi-cylindre de carotte après polissage

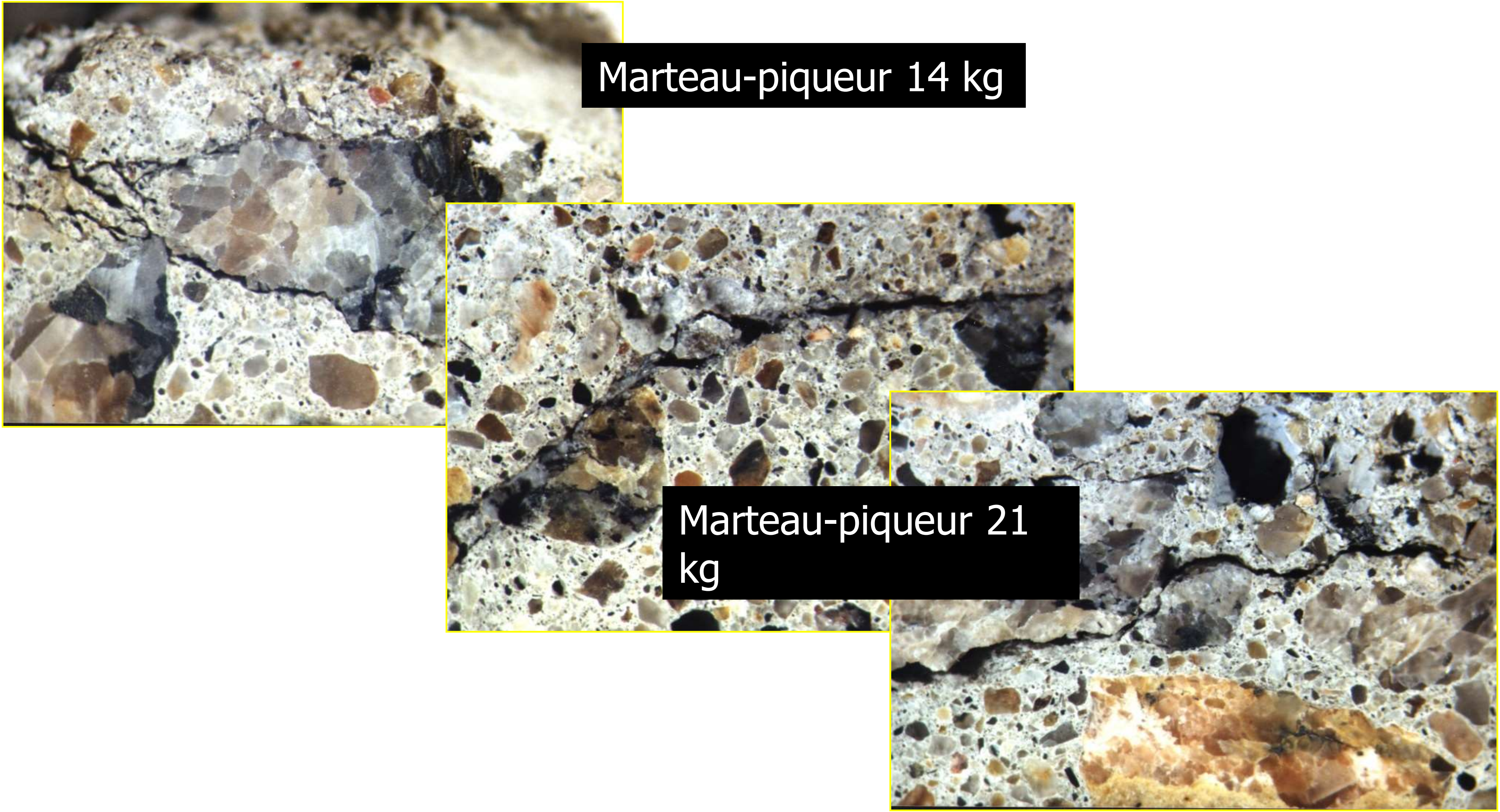
Concrete removal techniques: influence on residual cracking and bond strength. B. Bissonnette, L. Courard, A. Vaysburd and N. Bélair. Concrete International, 28(12) 2006, 49-55

Préparation des surfaces
Critères d 'observation

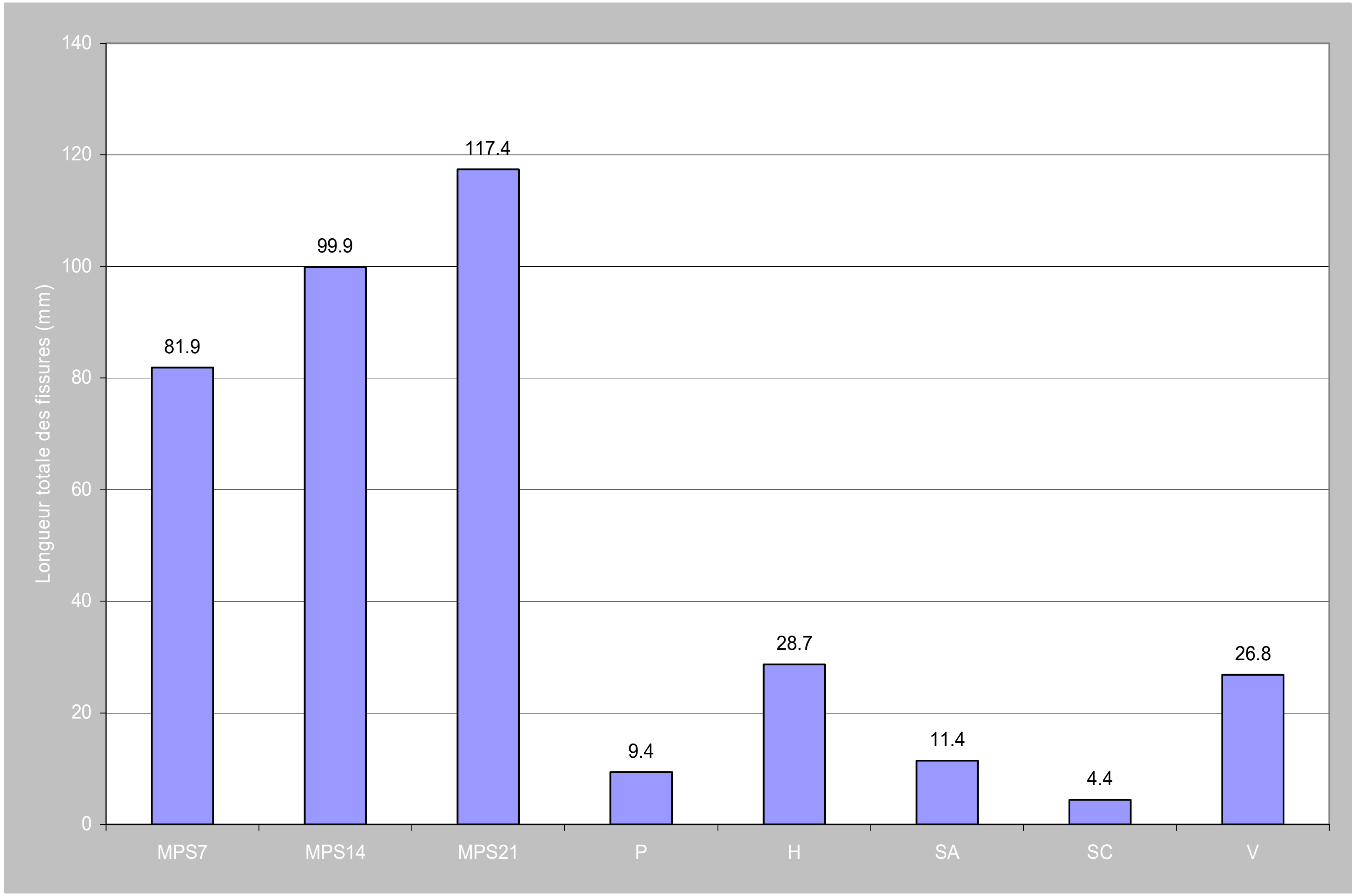
- nombre de fissures
- largeur et longueur des fissures
- profondeur maximum des fissures
- longueur géométrique du profil
- longueur réelle du profil

Préparation des surfaces

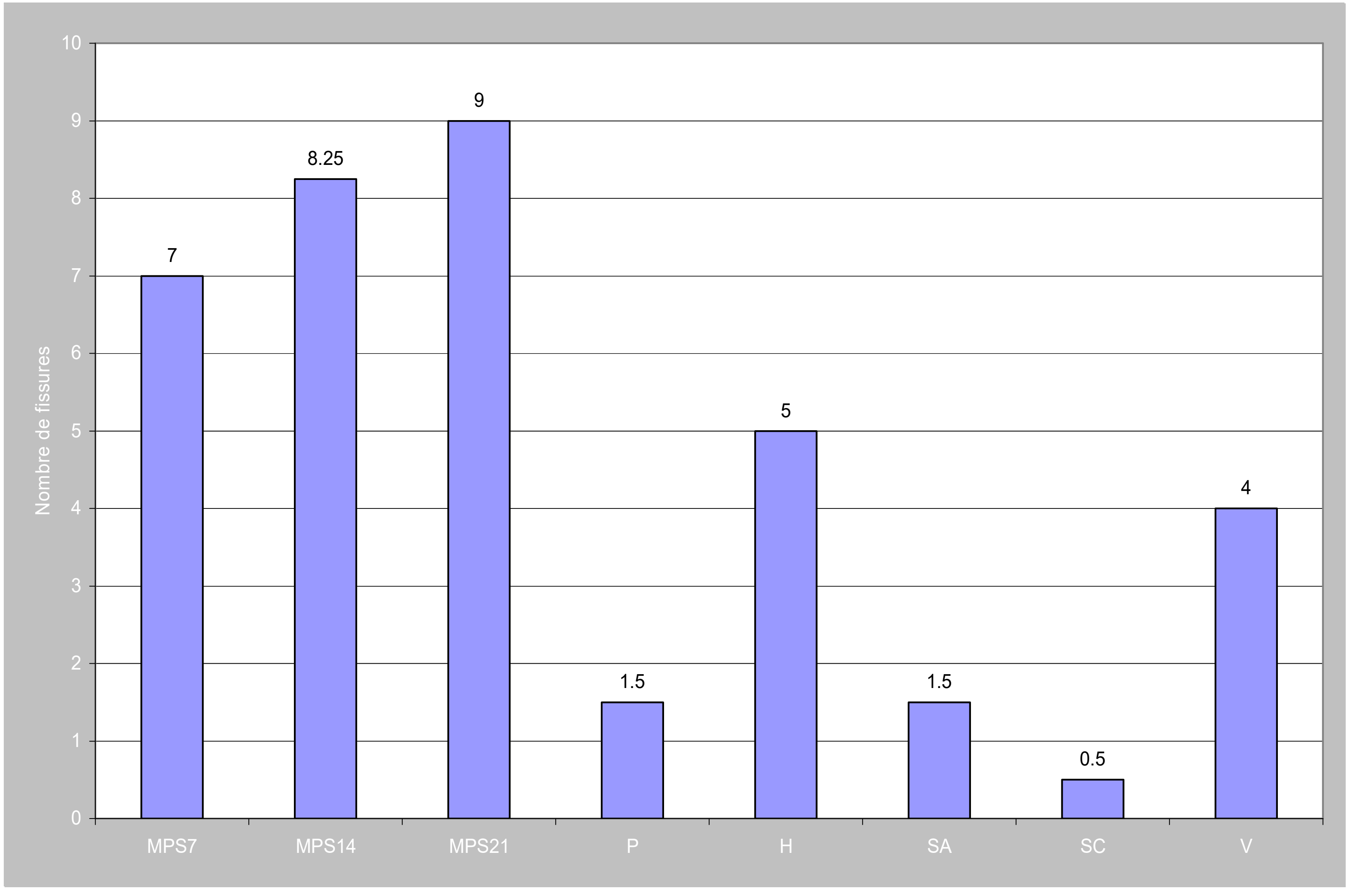
Prélèvements



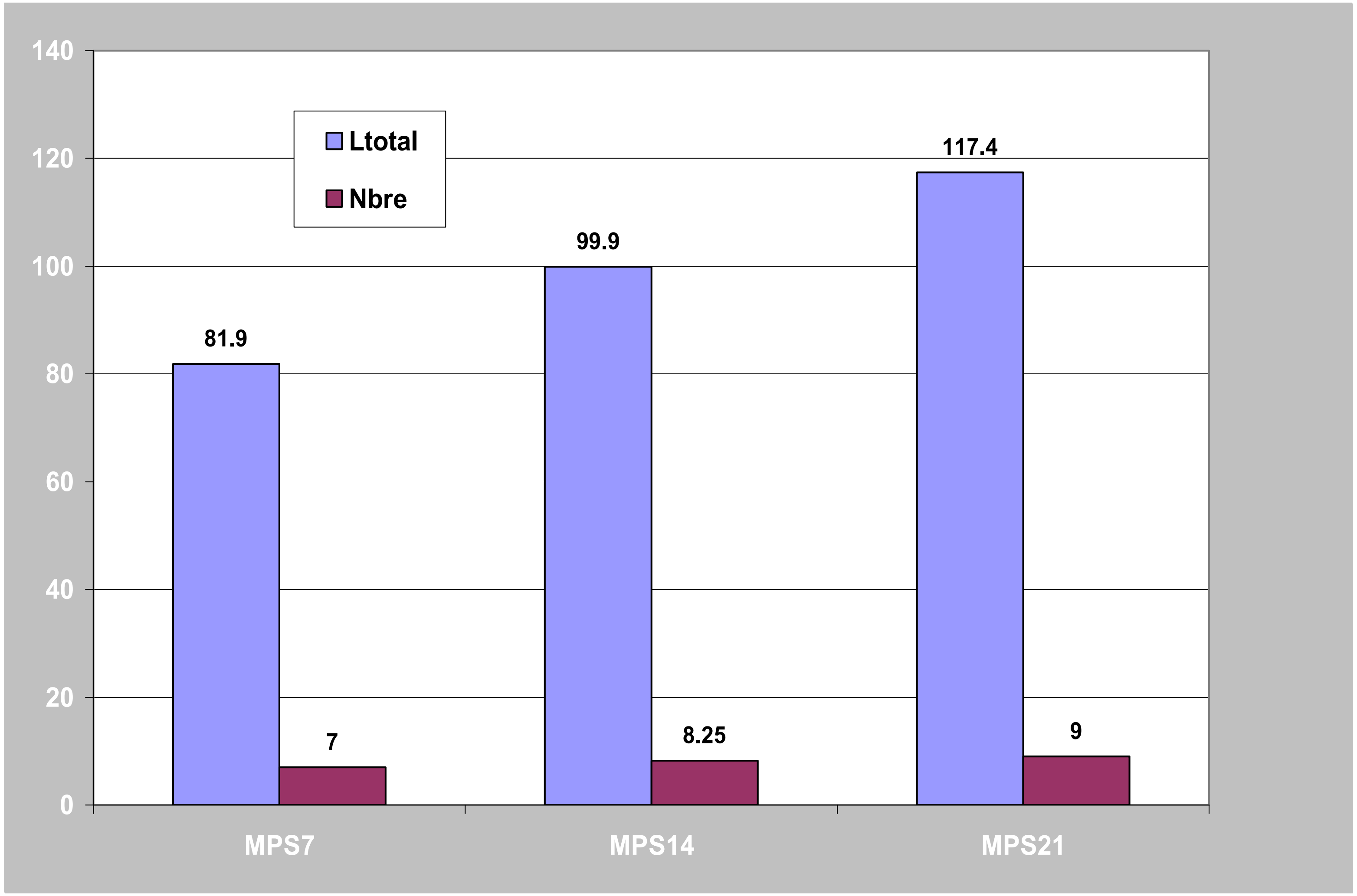
Préparation des surfaces
Longueur totale des fissures



Préparation des surfaces
Nombre de fissures



Préparation des surfaces

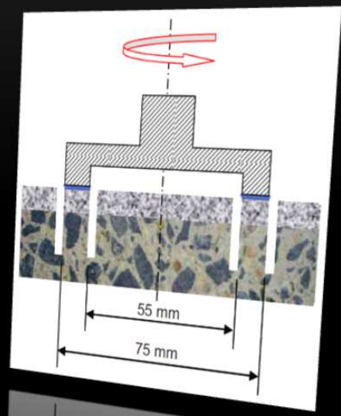


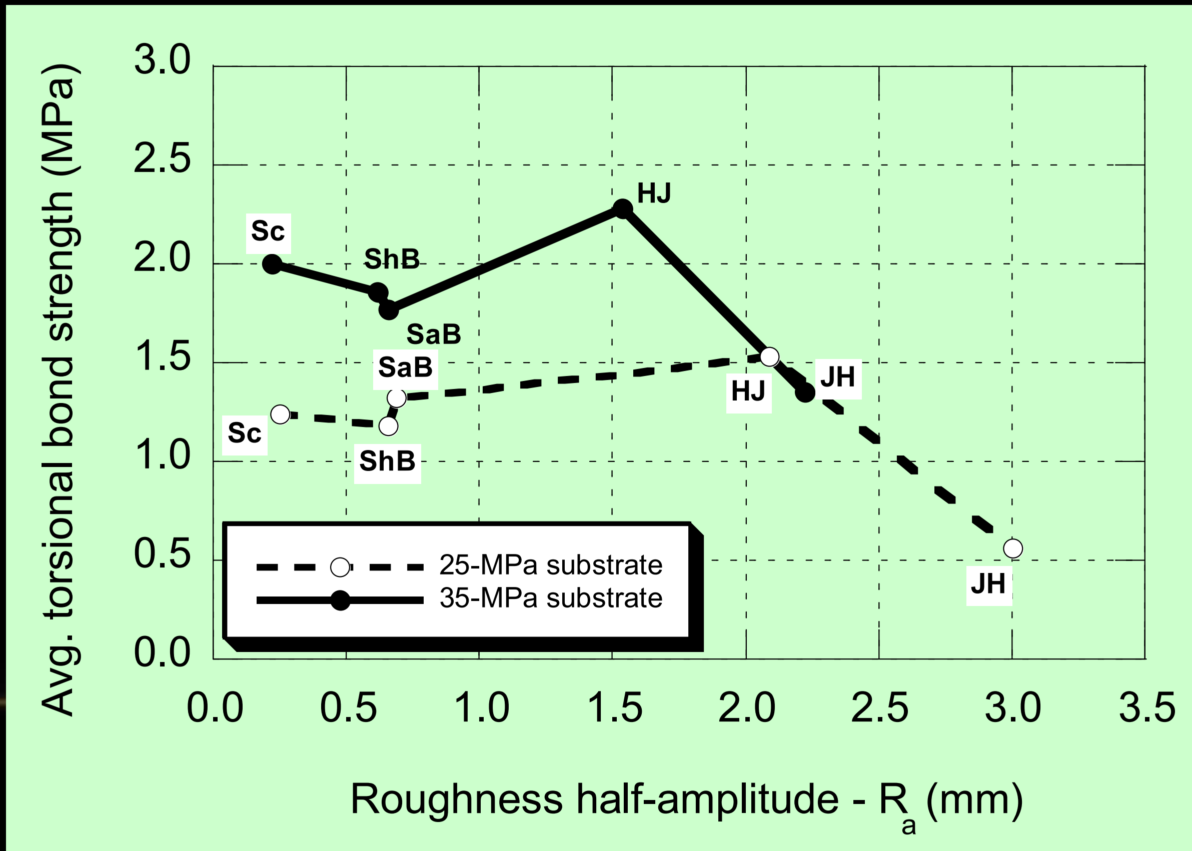
Préparation des surfaces

- le nombre de fissures est plus élevé pour la préparation au marteau-piqueur;
- la longueur des fissures est significativement plus élevée pour la préparation au marteau-piqueur;
- la « scarification » et le sablage ne provoquent pas de dégradations majeures;
- l'hydro-démolition provoque une très légère décohésion superficielle du support;
- l'augmentation de l'énergie de choc induit une augmentation proportionnelle de la longueur et du nombre de fissures.

RESULTS & ANALYSIS

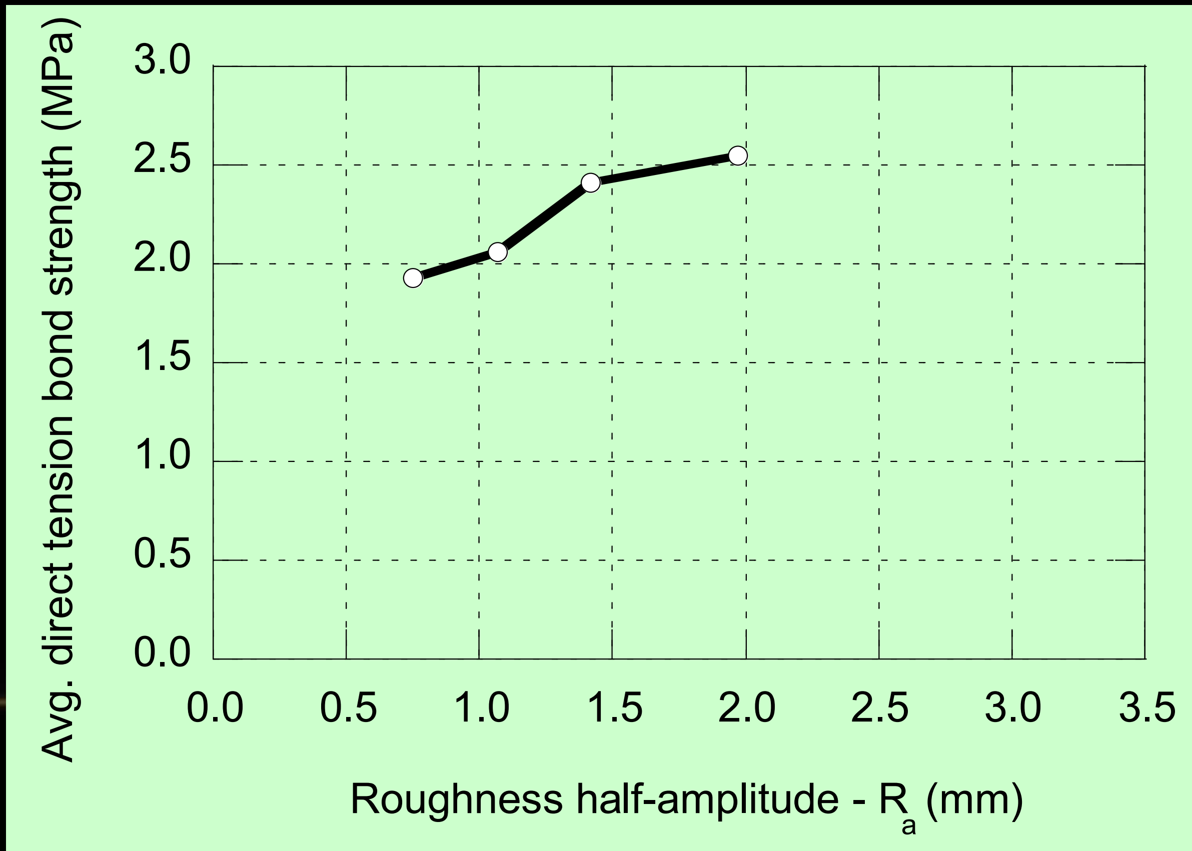
- Evaluation of bond strength
  - Torque testing (torsional/shear bond strength)





RESULTS & ANALYSIS

- Evaluation of bond strength
  - Pull-off testing (tensile bond strength) – *artificial profile*

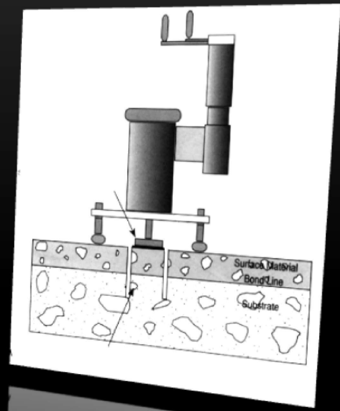


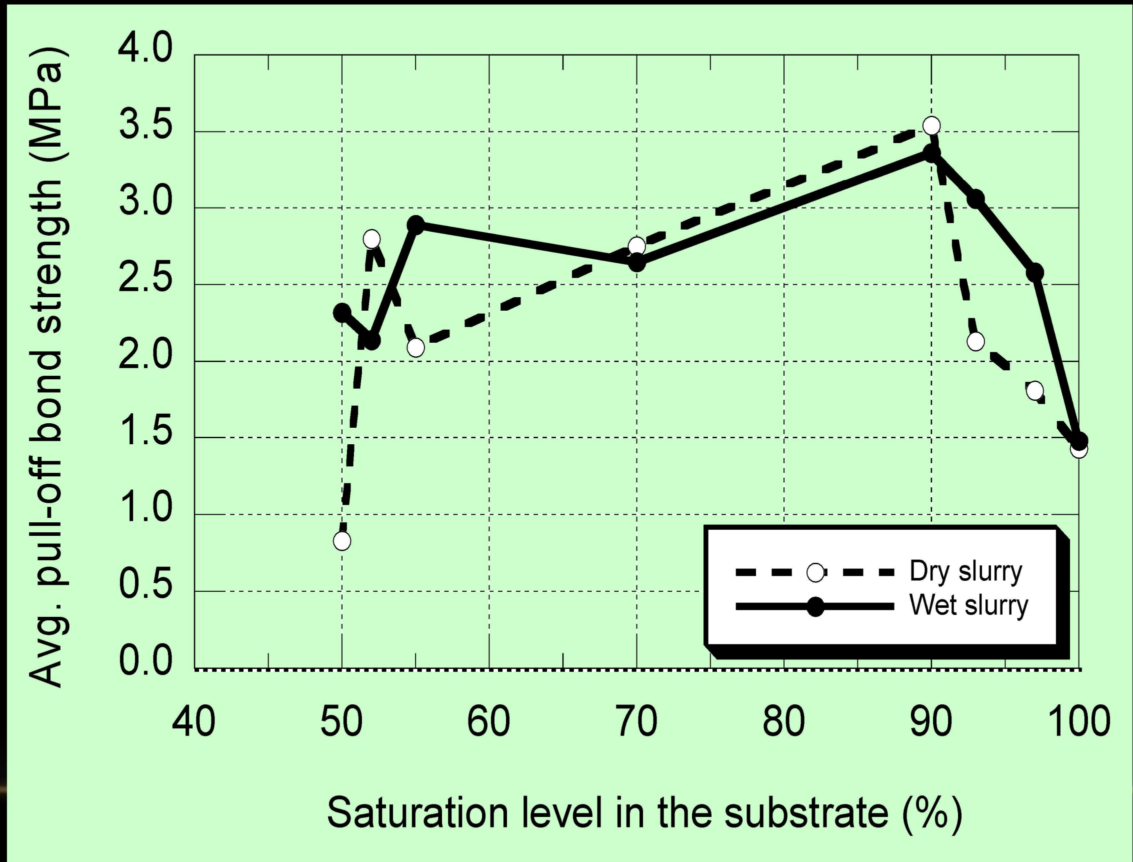
METHODOLOGY

- Influence of substrate moisture content
  - Series of test slabs prepared with three different concrete mixtures (30 MPa; 40 MPa; 50 MPa)
    - Various conditioning regimes to yield moisture levels covering the range from 30 to 100 % RH
    - Test slabs overlaid with OPC concrete (SB) after moisture conditioning
    - Optimum moisture content of the concrete substrate for repair bond
  - Test methods for evaluating the moisture content (indirect methods)
    - *Initial Surface Absorption* test (ISAT)
    - Modified version of the *Capillary Suction* test (MCST)

RESULTS & ANALYSIS

- Influence of moisture content



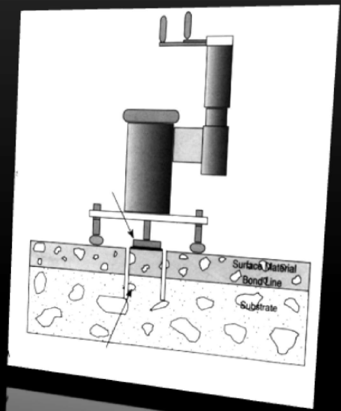


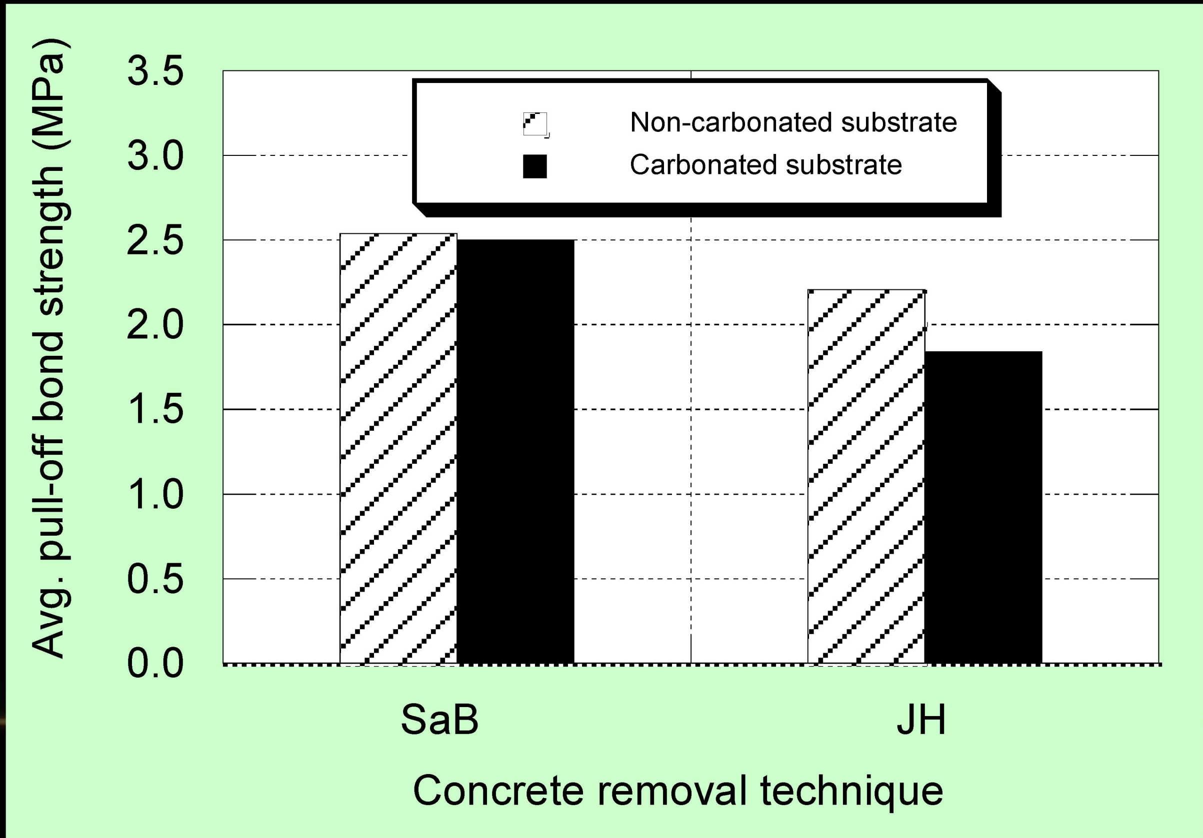
METHODOLOGY

- Influence of carbonation
  - Series of 400×400×100-mm test slabs (18) prepared with a 28-MPa concrete mixtures
    - Surface treatment
      - sandblasting (9 slabs)
      - light handheld jackhammer (9 slabs)
    - Conditioning
      - specimens protected from carbonation (control)
      - specimens exposed in a CO_2 chamber (depth measured with phenolphthalein)
    - Test slabs overlaid with OPC concrete after conditioning

RESULTS & ANALYSIS

- Influence of carbonation
  - After 3 months: d_c > 3 mm





Préparation de surface: adhérence mortier

Treatment type	Mean value [MPa] (coefficient of variation in %)	
	Repair mortar <u>with</u> bond coat	Repair mortar <u>without</u> bond coat
NT	1.92 (23.4)	2.28 (17.1)
GR	1.82 (15.9)	1.16 (50.9)
SB	1.93 (11.4)	1.82 (32.4)
SHB20	1.68 (18.5)	0.78 (39.7)
SHB35	1.94 (11.3)	1.25 (28.8)
SHB45	1.96 (32.7)	0.83 (25.3)
HMIL	1.42 (12.7)	1.01 (40.6)
MMIL	1.60 (24.4)	0.49 (57.1)

collaboration WUT,ULiège

CONCLUSION

- Pull-off testing is a convenient and useful test method
  - Evaluation of both the mechanical integrity of the concrete surface (prior to repair) and the repair bond strength
  - Reliable and practical QC tool
- The potential bias due to testing misalignment, below the average naked-eye detection capability, was evaluated to reach up to approximately 15 %
  - For QC testing, the bias can only affect the pull-off strength evaluation on the conservative side

CONCLUSION

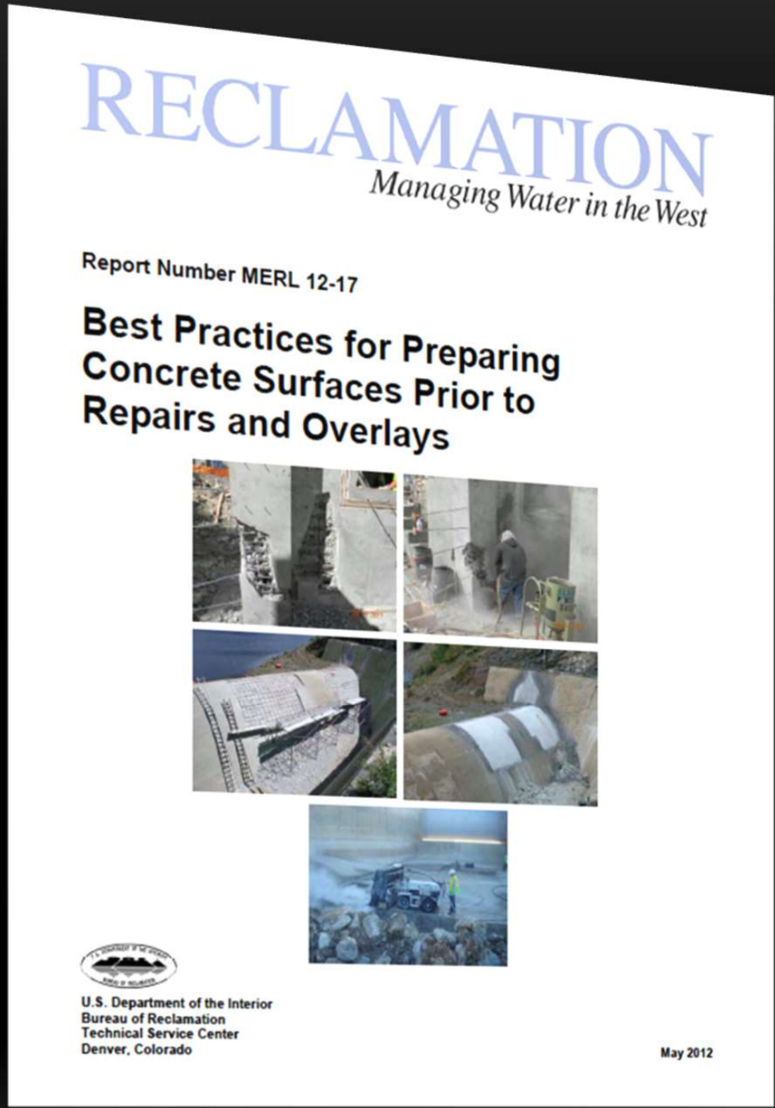
- Bond strength of concrete repairs depends on a number of parameters
  - In the absence of substrate-induced damage, tensile bond strength increases with the substrate roughness
  - Still, the most important parameter apparently remains the mechanical integrity of the substrate
  - In that regard, it must be stressed that the use of impacting methods such as jack hammering leaves significant damage at the surface, which can easily outweigh the benefits of an increased surface roughness

CONCLUSION

- The results obtained in the present study show that optimum moisture saturation levels for repair bond strength would lie somewhere between 55 to 90 % RH
- Carbonation appears in turn to have limited impact on repair bond strength for an otherwise sound, properly prepared concrete substrate surface

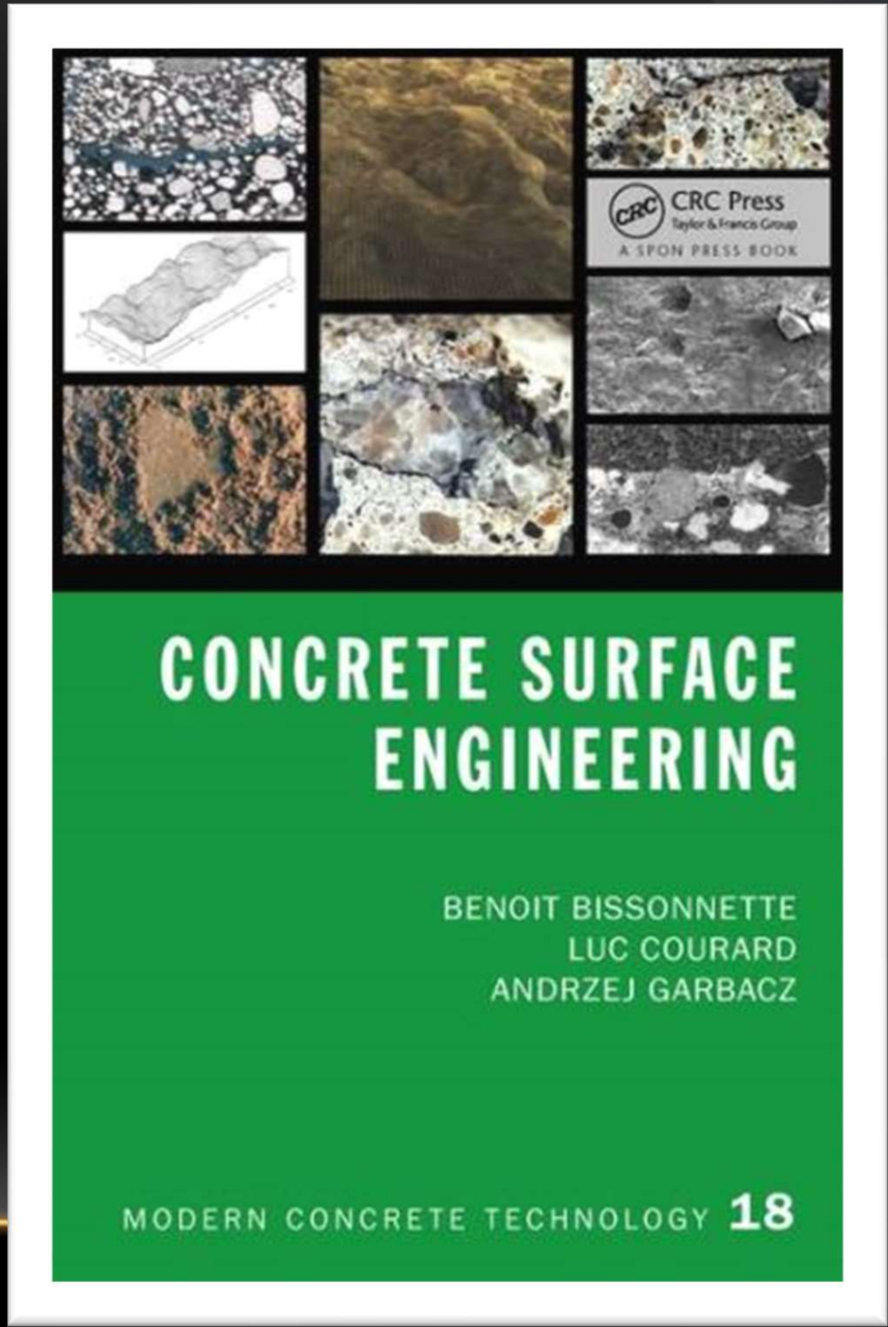
CONCLUSION

- A guideline was published by the U.S. Bureau of Reclamation
- Final Report ST-2017- 2886 -1
- www.usbr.gov/research/projects



CONCLUSIONS

- Concrete Surface Engineering, CRC Press



CONCLUSIONS

- Courard L., Bissonnette B., Vaysburd A., Bélair N., Lebeau F. (2012) Comparison of destructive methods to appraise the mechanical integrity of a concrete surface. Concrete Repair Bulletin 25(4), 22-30.
- Bissonnette B., Courard L. (2004) Pull-Off Test for the Evaluation of the Superficial Cohesion of Concrete Substrates in Repair Works: Analysis of the Test Parameters (FR), Materials and Structures 37, 342-350.

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